NSRDS-NBS 29

Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients From 10 keV to 100 GeV

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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[2] Located at Boulder, Colorado 80302.
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UNITED STATES DEPARTMENT OF COMMERCE
MAURICE H. STANS, *Secretary*,
U. S. **NATIONAL BUREAU OF STANDARDS** • A. V. ASTIN, *Director*

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Center for Radiation Research
National Bureau of Standards
Washington, D.C. 20234

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Foreword

The National Standard Reference Data System is a Government-wide effort to provide for the technical community of the United States effective access to the quantitative data of physical science, critically evaluated and compiled for convenience, and readily accessible through a variety of distribution channels. The System was established in 1963 by action of the President's Office of Science and Technology and the Federal Council for Science and Technology.

The responsibility to administer the System was assigned to the National Bureau of Standards and an Office of Standard Reference Data was set up at the Bureau for this purpose. Since 1963, this Office has developed systematic plans for meeting high-priority needs for reliable reference data. It has undertaken to coordinate and integrate existing data evaluation and compilation activities (primarily those under sponsorship of Federal agencies) into a comprehensive program, supplementing and expanding technical coverage when necessary, establishing and maintaining standards for the output of the participating groups, and providing mechanisms for the dissemination of the output as required.

The System now comprises a complex of data centers and other activities, carried on in Government agencies, academic institutions, and nongovernmental laboratories. The independent operational status of existing critical data projects is maintained and encouraged. Data centers that are components of the NSRDS produce compilations of critically evaluated data, critical reviews of the state of quantitative knowledge in specialized areas, and computations of useful functions derived from standard reference data. In addition, the centers and projects establish criteria for evaluation and compilation of data and make recommendations on needed modifications or extensions of experimental techniques.

Data publications of the NSRDS take a variety of physical forms, including books, pamphlets, loose-leaf sheets and computer tapes. While most of the compilations have been issued by the Government Printing Office, several have appeared in scientific journals. Under some circumstances, private publishing houses are regarded as appropriate primary dissemination mechanisms.

The technical scope of the NSRDS is indicated by the principal categories of data compilation projects now active or being planned: nuclear properties, atomic and molecular properties, solid state properties, thermodynamic and transport properties, chemical kinetics, colloid and surface properties, and mechanical properties.

An important aspect of the NSRDS is the advice and planning assistance which the National Research Council of the National Academy of Sciences-National Academy of Engineering provides. These services are organized under an overall Review Committee which considers the program as a whole and makes recommendations on policy, long-term planning, and international collaboration. Advisory Panels, each concerned with a single technical area, meet regularly to examine major portions of the program, assign relative priorities, and identify specific key problems in need of further attention. For selected specific topics, the Advisory Panels sponsor subpanels which make detailed studies of users' needs, the present state of knowledge, and existing data resources as a basis for recommending one or more data compilation activities. This assembly of advisory services contributes greatly to the guidance of NSRDS activities.

The NSRDS – NBS series of publications is intended primarily to include evaluated reference data and critical reviews of long-term interest to the scientific and technical community.

A. V. Astin, *Director.*

Contents

Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients From 10 keV to 100 GeV*

J. H. Hubbell

This report updates and extends previous NBS tabulations. Section 1 contains the information of most immediate practical use: (a) a tabulation of the attenuation coefficient for 23 elements ($_1$H to $_{92}$U) between 10 keV and 100 GeV and (b) a tabulation of the energy absorption coefficient for air, water, and 18 elements between 10 keV and 10 MeV, and for air, water, and 7 elements up to 100 MeV. Section 2 contains detailed information on the predominant processes (photoelectric absorption, Compton scattering and pair production) and a brief discussion of other processes which combine to give the attenuation coefficient. Theoretical and experimental data are reviewed, and auxiliary tables and approximation formulas are given. Section 3 contains tabulations of cross sections for the predominant processes between 10 keV and 100 GeV for 23 elements and for 13 compounds and mixtures.

Key words: Attenuation coefficient; Compton scattering; cross section; energy absorption coefficient; gamma rays; pair production; photoelectric absorption; photons; x-rays.

1. Attenuation and Energy Absorption Coefficients

1.1. Introduction

The first modern systematic compilation of photon [1] interaction cross sections and attenuation coefficients, covering the energy range 10 keV to 100 MeV, was done by White [2] [1952] and appeared in NBS Report 1003 (unpublished).[3] Her tables were subsequently published in the Handbook of Radiology [1955] and in the 1955 edition of Beta and Gamma-Ray Spectroscopy [1955]. Storm, Gilbert, and Israel [1958] further extended these tables by interpolation to include all elements from $Z = 1$ to 100.

With some revisions the tables from NBS Report 1003 were published in NBS Circular 583 [1957], and were revised in the 10–100 keV region by McGinnies [1959] in NBS Circular 583 (Supplement). Davisson [1965] further updated these tables using more recent theoretical estimates of atomic photoeffect and electron-field pair production.[4]

The present compilation, an earlier version of which has been presented elsewhere (Hubbell and Berger [1968]), is based on a new analysis of all available information. We were of course guided strongly by methods and results contained in previous compilations, particularly those of White [1952], but have also gone back to the original experimental and theoretical literature.

We retain the format of White for the main tables (sec. 3) but we have extended the energy range up to 100 GeV and have taken into account new data including the following:

(a) Photoeffect calculations by Hultberg et al. [1968], Rakavy and Ron [1965–7] and Pratt and Schmickley [1967].
(b) Calculations of double Compton scattering and radiative corrections to Compton scattering by Mork [1968].
(c) Nuclear-field pair-production radiative corrections calculated by Mork and Olson [1965] and screening effects evaluated by Sörenssen [1965–6].
(d) Electron-field pair-production calculations by Mork [1967] which combine Votruba's [1948] theory with that of Borsellino [1947] and Ghizzetti [1947], and include the radiative correction.
(e) Calculations of coherent and incoherent scattering by Storm and Israel [1967].
(f) Additional experimental data including, among others, the total cross section measurements by Barkan [1956], Wiedenbeck [1962], Barlett and Donahue [1963, 1965], Heinrich [1966], Hughes and Woodhouse [1966], Carter et al. [1967], McCrary, Plassman et al. [1967], Perkin and Douglas [1967], and Knerr and Vonach [1967].

*Supported primarily by the NBS Office of Standard Reference Data. Support was also received from the Defense Atomic Support Agency.

[1] The terms "x-ray," "gamma-ray," and "photon" are used interchangeably throughout this work.

[2] Referred to in her later work [1957], as White-Grodstein.

[3] Earlier compilations which are partly theoretical, and which cover less extensive or lower energy ranges, include those of Jönsson [1927–8], Victoreen [1943–9], Woo and Sun [1947], Davisson and Evans [1952], and G. Allen [1950–1967]. The well-known data of S. J. M. Allen [1930–1967] appearing in the Handbook of Chemistry and Physics are experimental and have not been revised since 1933.

[4] Davisson's [1965] tables are accompanied by an extensive review article. Other reviews include those by Latyshev [1947], Bethe and Ashkin [1953], Fano [1953], Evans [1955, 1963], Hayward [1958], Fano, Spencer, and Berger [1959], Fano, Zerhy, and Berger [1962], and Koch, MacGillavry, and Milledge [1962]. For further references to original data and to other compilations there are available extensive bibliographies by Glocker [1950] and Stainer [1963] in the low energy region and by Toms [1965] in the high energy region.

In addition, we tabulate various related coefficients that can be used to compute the transfer of energy to the medium, namely: (a) the mass energy-absorption coefficient, (b) the mass energy-transfer coefficient, and (c) the mass absorption coefficient.[5] These coefficients were obtained by updating and extending the work of R. Berger [1961] and Allison [1961].

In the present work we have taken 10 keV as a lower limit on the energy range considered. Tabulations which extend to lower energies include those by Brown [1966] ($Z=1$ to 100; 1 keV–10 MeV), McMaster et al. [1967] (87 elements $Z=1$ to 94; 1 keV–1 MeV), and by Storm and Israel [1967] ($Z=1$ to 100; 1 keV–100 MeV). For light elements at lower energies, Henke et al. [1967] have used their own experimental data and those of others to provide a compilation of attenuation coefficients versus energy for the 17 elements He through Ar over the energy range 0.030 to 6.0 keV. Additional low-energy attenuation coefficient tabulations for use by electron microprobe analysts (the coefficients are given at characteristic x-ray emission wavelengths) include, among others, those by Birks [1963], Heinrich [1966], Frazer [1967], and Theisen and Vollath [1967].

1.2. Physical Constants; Units; Notation

1.2.1. Physical Constants and Conversion Factors[6]

Z	atomic number,
M	atomic weight in g/g-*atom*,
m	electron rest-mass $=9.1091\cdot10^{-28}$ g,
mc^2	electron rest-mass energy $=5.11006\cdot10^{5}$ eV,
c	velocity of light $=2.997925\cdot10^{10}$ cm s^{-1},
e	elementary charge $=1.60210\cdot10^{-19}$ Coulomb $=4.80298\cdot10^{-10}$ cm$^{3/2}$g$^{1/2}$s^{-1} (e.s.u.),
r_e	classical electron radius $=e^2/(mc^2)=2.81777\cdot10^{-13}$ cm,
r_e^2	$=7.9398\cdot10^{-26}$ cm^2,
σ_T	cross section for classical Thomson scattering from an electron $=8\pi r_e^2/3=6.6516\cdot10^{-25}$ cm^2,
N_A	Avogadro constant $=6.02252\cdot10^{23}=$ atoms/mole,
α	fine structure constant $=7.29720\cdot10^{-3}=1/137.0388\approx1/137$,
E	photon energy in eV units (e.g.: keV, MeV or GeV),
k	photon energy in units of the electron rest-mass energy (i.e., mc^2 units) $=E$[MeV]/0.511006,
q	momentum transfer to an atom or electron in units of mc,
λ	photon wavelength in Compton units $=1/k=0.511006/E$[MeV],
λ(Å)	photon wavelength in angstroms (1 angstrom $=10^{-8}$ cm) $=1.23981\cdot10^{-2}/E$[MeV][7]
b	barn $=10^{-24}$ cm^2.

[5] For definitions of these coefficients see Secs. 1.2. and 1.5. A great variety of names and symbols have been used for these coefficients, and readers interested in the nomenclature used by various authors should consult R. Berger [1961].

[6] *Note:* Numerical values given here are those recommended in 1964 by the Committee on Fundamental Constants of the National Academy of Sciences—National Research Council [1964]. They are based on the atomic weight scale in which $M=12.0000$ for C^{12}.

[7] In addition to the angstrom, which is based on the centimeter, two photon wavelength units, Å* and *xu*, are in use which are based on characteristic x-ray emission wavelengths. The recently-introduced Å*-unit (Bearden [1967]) is presently identical with the angstrom within an uncertainty of 5 ppm. i.e.:

$$1\text{Å}^*=1\text{Å}\pm5\text{ ppm}.$$

The tungsten $K\alpha_1$ emission line has been recommended by Bearden as the x-ray wavelength primary standard with the value

$$\lambda(WK\alpha_1)\equiv0.2090100\text{ Å}^*$$

and hence

$$\lambda(WK\alpha_1)=0.2090100\text{Å}\pm5\text{ ppm}.$$

The *x*-unit (*xu*), used in much of the older literature and occasionally in the present literature, was intended to be 10^{-3}Å but has taken on a variety of values because of errors and inconsistencies in the various wavelength standards used. If the molybdenum $K\alpha_1$, emission line is taken as a reference with the value (Bearden [1967]):

$$\lambda(\text{Mo }K\alpha_1)\equiv707.831\ xu$$

then

$$1\ xu=1.002056\cdot10^{-3}\text{ Å}^*$$

and

$$\lambda(xu)=12.37/E(\text{MeV}).$$

1.2.2. Notation and Units

Symbol	Name or definition	Units	Where used
μ	"narrow beam" linear attenuation coefficient	cm^{-1}	Table 1.–5; Eqs (1.–1) to (–4)
ρ	absorber density	g cm^{-3}	Tables 1.–, 2
μ/ρ	mass attenuation coefficient $=\sigma_{tot}$ [b/atom] $\cdot (N_A/M) \cdot 10^{-24}$ $[(cm^2g^{-1})/(b/atom)]$	cm^2 g^{-1}	Tables 1.–4; 3.–1 to 36; Eqs (1.–5) to (–7)
mfp	mean free path$=1/\mu$, $=1/(\mu/\rho)$	cm g cm^{-2}	Eq (1.–4a) Fig 1.–2
$t_{1/2}$	Half-value layer$=0.69315/\mu$, $=0.69315/(\mu/\rho)$	cm g cm^{-2}	Eq (1.–4b) Fig 1.–2
$t_{1/10}$	1/10–value layer$=2.3026/\mu$, $=2.3026/(\mu/\rho)$	cm g cm^{-2}	Eq (1.–4c) Fig 1.–2
ΔV	"volume of interest" in a medium, for photon energy transfer estimates	cm^3	Eq (1.–9)
μ_{en}/ρ	mass energy-absorption coefficient, allowing for escape from the volume of interest of all secondary photons, including bremsstrahlung, as given in definition (17) in NBS Handbook 85 (ICRU Rep. 10b) [1964]	cm^2 g^{-1}	Fig 1.–3; Tables 1.–7, 8, 9; Eq (1.–10)
μ_K/ρ	mass energy-transfer coefficient allowing only for the escape of Compton-scattered, fluorescence and annihilation photons, as given in definition (16) in NBS Handbook 85 (ICRU Rep. 10b) [1964]	cm^2 g^{-1}	Tables 1.–7, 8
μ_a/ρ	mass absorption coefficient allowing for escape of Compton scattered photons only, as defined in eq (8f–48) of Evans [1963]	cm^2 g^{-1}	Tables 1.–7, 8, 9
f_τ	average fraction of photon energy transferred to the medium as a result of photoelectric absorption	dimensionless	Eq (1.–10)
f_C	average fraction of photon energy transferred to the medium as a result of a Compton collision	dimensionless	Eqs (1.–10), (2.–13) Table 2.–8
f_κ	average fraction of photon energy transferred to the medium as a result of a pair production event	dimensionless	Eq (1.–10)
R_e	electron range (here used in the "continuous-slowing-down-approximation")	g cm^{-2}	Table 1.–6
σ_{tot}	total photon interaction cross section per atom (defined in this paper to include only photoelectric absorption, Compton collision, and pair production)	b/atom	Eqs (1.–5), (2.–24); Fig 2.–1
τ_{pe}	total photoelectric absorption cross section per atom$=\tau_K+\tau_L+\cdots$	b/atom	Sec. 2.3.; Tables 2.–4, 5, 3.–1 to 3.–23; Fig 2.–1
μ_τ/ρ	τ_{pe} [b/atom] $\cdot (N_A/M) \cdot 10^{-24}$ $[(cm^2g^{-1})/(b/atom)]$	cm^2 g^{-1}	Eq (1.–10)
$\tau_K, \tau_L \ldots$	photoelectric absorption cross section per atom for K-shell electrons, L-shell electrons, etc.	b/atom	Table 2.–6; Eq (2.–1)
τ_{pe}/τ_K	ratio of total photoelectric to K-shell photoelectric cross section (above the K-edge) $=\dfrac{\tau_K+\tau_L+\tau_M+\cdots}{\tau_K}=\dfrac{\delta}{\delta-1}$, where δ is the K-edge "jump ratio" $\dfrac{\tau_K+\tau_L+\tau_M+\cdots}{\tau_L+\tau_M+\cdots}$ as defined by Kirchner [1930]	dimensionless	Table 2.–6 Eq (2.–2)

Symbol	Name or definition	Units	Where used
σ_C	Compton ("incoherent") collision cross section	b/electron or b/atom	Sec. 2.4.; Table 2.–8; Eq (1.–8); Fig. 2.–1
μ_C/ρ	σ_C[b/atom] · $(N_A/M) \cdot 10^{-24}$ [$(cm^2 g^{-1})$/(b/atom)]	$cm^2\ g^{-1}$	Eq (1.–10)
σ_C^{KN}	σ_C as given by the Klein-Nishina formula	b/electron	Table 2.–8; Eqs (2.–8), (–9), (–11)
σ_C^{H}	σ_C as given by Hasting's empirical fit to σ_C^{KN}	b/electron	Eq (2.–12)
σ_C^{BD}	σ_C for bound electrons	b/electron or b/atom	Sec. 2.4.2; Eq (2.–18); Fig. 2.–3
σ_C^{K}	σ_C for a K-shell electron	b/electron	Fig 2.–2
$S(q, Z)$	incoherent scattering function	dimensionless	Eq (2.–18)
σ_R	Rayleigh ("coherent") scattering cross section per atom	b/atom	Sec. 2.4.2; eq (2.–22); Fig. 2.–4
$F(q, Z)$	atomic form factor	dimensionless	Eq (2.–22)
θ_c	criterion angle for assessing importance of Rayleigh scattering	degrees or radians	Eq (2.–23); Fig. 2.–4
σ("scattering, with coherent")	total bound-electron scattering cross section $=\sigma_C^{BD}+\sigma_R$	b/atom	Sec. 2.4.2; Tables 2.–9, 3.–1 to –23
$\Delta\sigma_C^{M}$	Mork correction to $\sigma_C=\sigma$ (double Compton)$+\sigma$ (radiative correction)	b/electron	Tables 2.–8; Eq (2.–25)
σ("scattering, without coherent")	free-electron scattering cross section, including radiative corrections $=\sigma_C^{KN}+\Delta\sigma_C^{M}$	b/electron or b/atom	Tables 2.–8, 3.–1 to –23
κ	total pair production cross section$=\kappa_n+\kappa_e$	b/atom	Sec. 2.5; Eq (2.–42)
μ_κ/ρ	κ[b/atom]$\cdot(N_A/M)\cdot 10^{-24}$ [$(cm^2\ g^{-1})$/(b/atom)]	$cm^2\ g^{-1}$	Eq (1.–10)
κ_n	cross section for pair production in the field of an atomic nucleus	b/atom	Sec. 2.5.2: Tables 2.–10, 3.–1 to –23; Eqs (2.–26), (–30), (–31)
κ_e	cross section for pair production in the field of the atomic electrons ("triplet" production)	b/atom	Sec. 2.5.3; Tables 2.–15, 3.–1 to –23; Eqs (2.–27), (–38), (–39)
η	$Z\cdot(\kappa_e/\kappa_n)$	dimensionless	Secs. 2.5.1, 2.5.3; Table 2.–15; Eqs (2.–41) to (–43)
κ_n^{BH}(Born)	κ_n as formulated by Bethe and Heitler in the Born approximation	b/atom	Table 2.–11; Eqs (2.–30), (–31), (–33), (–34), (–36)
$-\Delta\kappa_n^{DBM}$	Davies-Bethe-Maximon Coulomb correction to κ_n^{BH}(Born)	b/atom	Table 2.–12; Eqs (2.–28), (–30), (–31)
s^{HFS}	Hartree-Fock-Slater screening corrections to κ_n	b/atom	Table 2.–13; Eq (2.–31)
$\sigma_{ph.\,n.}$	total photonuclear cross section $=\sigma(\gamma,\ n)+\sigma(\gamma,\ p)+\cdots$	b/atom or mb/atom	Sec. 2.–6; Eq (2.–44)
E_0	energy at which the maximum, σ_0, of the $\sigma_{ph.\,n.}$ resonance peak occurs	MeV	Table 2.–16; Eq (2.–44)
Γ	width at half-max. of the $\sigma_{ph.\,n.}$ peak	MeV	Table 2.–16; Eq (2.–44)

1.3. Definition and Significance of Narrow-Beam Attenuation Coefficient

The most important quantity characterizing the penetration and diffusion of gamma radiation in extended media is the attenuation coefficient, μ. This quantity depends on the photon energy E and on the atomic number Z of the medium, and may be defined as the probability per unit pathlength that a photon will interact with the medium.

Consider, as a typical situation, a slab of material of thickness t located between a narrowly collimated source of monoenergetic gamma ray photons and a narrowly collimated detector, as indicated in figure 1.–1. In a layer dx within the slab there will occur a reduction of the intensity, I, of the gamma ray beam, due to:

(1) outright absorption, or

(2) scattering out of the beam.

The resulting fractional reduction of the beam intensity, $-dI/I$, is proportional to the "narrow beam" attenuation coefficient, μ, and to the layer thickness, dx, i.e.,

$$-dI/I=\mu\ dx. \tag{1.–1}$$

Integrating this equation and assuming that the beam intensity incident on the slab has the value I_0, one obtains for the intensity transmitted through the slab the value

$$I(t)=I_0 \exp\left\{-\int_0^t \mu(x)dx\right\}. \tag{1.–2}$$

For a homogeneous medium this reduces to

$$I(t)=I_0\, e^{-\mu t}. \tag{1.–3}$$

For situations more complicated than the narrow-beam experiment, the attenuation is still basically exponential but is modified by two additional factors. The first of these, sometimes called a "geometry factor," depends essentially on the source geometry and involves, for example, the insertion of the inverse square law in eq (1.–3) for a point isotropic source. The other factor, often called the "buildup factor," takes into account secondary photons produced in the absorber (mainly as the result of one or more Compton scatters) which reach the detector. The determination of such buildup factors constitutes a large part of gamma ray transport theory.

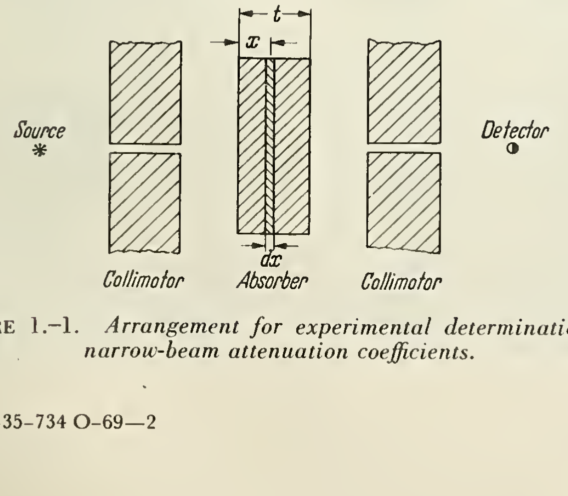

FIGURE 1.–1. *Arrangement for experimental determination of narrow-beam attenuation coefficients.*

In the narrow-beam equation (1.–3), the absorber thickness t in which the beam intensity is reduced by a factor e (i.e., $I/I_0=1/e=0.36788$), is called the mean-free-path. One mean-free-path (mfp) also represents the average distance traveled by a photon between successive interactions. Analogous quantities are the half-value layer and one-tenth-value layer, $t_{1/2}$ and $t_{1/10}$, in which the intensity is reduced by $\frac{1}{2}$ and $\frac{1}{10}$, respectively.[7a] These quantities can be evaluated graphically from an experimental narrow beam attenuation curve, as indicated in figure 1.–2 for ^{137}Cs ($E=0.662$ MeV) gamma rays in concrete and lead. They are related to the attenuation coefficient according to

$$1 \text{ mfp}=1/\mu, \tag{1.–4a}$$

$$t_{1/2}\ =(-\ln \tfrac{1}{2})/\mu=0.69315/\mu, \tag{1.–4b}$$

and

$$t_{1/10}\ =(-\ln \tfrac{1}{10})/\mu=2.3026/\mu. \tag{1.–4c}$$

From the above discussion it is apparent that the attenuation coefficient μ has dimensions of an inverse length. Hence, if t is in cm, in, ft, etc., the corresponding values of μ must be in units of cm^{-1}, in^{-1}, ft^{-1}, etc., and as such are called "linear attenuation coefficients". However, although linear attenuation coefficients are convenient for engineering application, they are proportional to the absorber density, ρ, which usually does not have a unique value but depends to some extent on the physical state of the material. Therefore, it is common practice, for purposes of tabulation, to remove this density dependence and to use the "mass attenuation coefficient" μ/ρ which, if μ is in cm^{-1} and ρ is in g/cm^3, will be in the customary units of cm^{-2}/g.

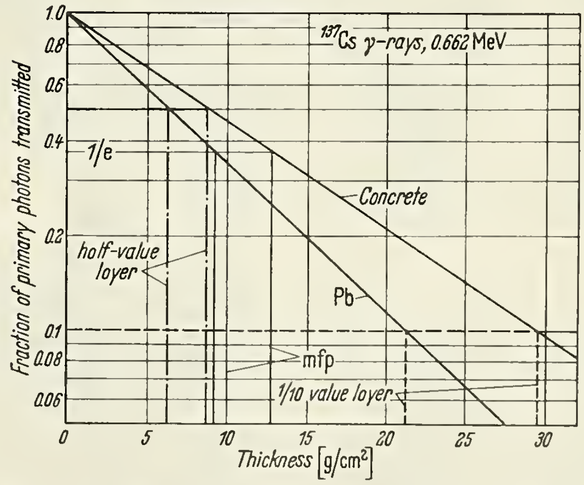

FIGURE 1.–2. *Semilog plot of narrow-beam attenuation of ^{137}Cs (0.662 MeV) gamma rays in lead and concrete.*

Graphical determinations of the mean-free-path and of the 1/2- and 1/10-value layers are indicated.

[7a] It should be noted that the ICRU (see, for example, NBS Handbook 85 [1964]) defines a half-value layer (HVL) in terms of exposure rate (intensity weighted by the ability of the radiation to produce ion pairs in air) rather than intensity. The difference between these definitions can lead to different half-value layer thicknesses if the source is not monoenergetic.

The mass attenuation coefficient μ/ρ is proportional to the total photon interaction cross section per atom, σ_{tot}, i.e., to the sum of the cross sections for all the elementary scattering and absorption process. This relation is

$$\frac{\mu}{\rho}\left[\frac{\text{cm}^2}{\text{g}}\right]=\sigma_{tot}\left[\frac{\text{cm}^2}{\text{atom}}\right]\cdot\frac{N_A\left[\dfrac{\text{atoms}}{\text{g-atom}}\right]}{M\,\dfrac{\text{g}}{\text{g-atom}}},$$

$$=\sigma_{tot}\left[\frac{\text{b}}{\text{atom}}\right]\cdot N_A/M\cdot 10^{-24}, \quad (1.\text{–}5)$$

where N_A is Avogadro's number ($6.02252\cdot 10^{23}$ atoms/g-atom) and M is the atomic weight of the absorber material. Table 1.–1 lists values of $(N_A/M)\cdot 10^{-24}$ for a number of elements, in addition to typical values for ρ, and similar information is given in table 1.–2 for some mixtures. The cross section per atom, σ_{tot}, should be used in preference to μ/ρ as a basis for interpolation vs. Z because of the dependence of μ/ρ on the atomic weight, M. Not only does M vary irregularly from element to element, but values of M can differ from those given in table 1.–1 depending on the isotopic composition of a given sample. The effects of isotopic variation on σ_{tot} (excluding photonuclear interactions) are negligible in comparison with effects on μ/ρ.

TABLE 1.–1. *Values of the atomic weight* M, *the factor* (N_A/M) $\times 10^{-24}$ *for converting attenuation data from b/atom to* cm^2g^{-1}, *and typical densities* ρ *for converting from* cm^2g^{-1} *to* cm^{-1}.

Element		M,* atomic wt.	$\frac{N_A}{M}\times 10^{-24}$**	ρ***
Z	Sym-bol	$g/g-atom$	$\frac{cm^2}{g}\Big/\frac{b}{atom}$	g/cm^3
1	H	1.00797	0.5975	0.00008988 g, (H_2)
2	He	4.0026	.1505	.0001785 g
3	Li	6.939	.08679	.534
4	Be	9.0122	.06683	1.85
5	B	10.811	.05571	2.535
6	C	12.01115	.05014	2.25 (graphite)****
7	N	14.0067	.04300	.001250 g, (N_2)
8	O	15.9994	.03764	.001429 g, (O_2)
9	F	18.9984	.03170	.001696 g, (F_2)
10	Ne	20.183	.02984	.0008999 g
11	Na	22.9898	.02620	.971
12	Mg	24.312	.02477	1.74
13	Al	26.9815	.02232	2.70
14	Si	28.086	.02144	2.42
15	P	30.9738	.01944	1.8–2.7
16	S	32.064	.01878	1.96–2.07
17	Cl	35.453	.01699	.003214 g, (Cl_2)
18	Ar	39.948	.01508	.001784 g
19	K	39.102	.01540	.87
20	Ca	40.08	.01503	1.55

TABLE 1.–1. *Values of the atomic weight* M, *the factor* (N_A/M) $\times 10^{-24}$ *for converting attenuation data from b/atom to* cm^2g^{-1}, *and typical densities* ρ *for converting from* cm^2g^{-1} *to* cm^{-1}.—Continued

Element		M,* atomic wt.	$\frac{N_A}{M}\times 10^{-24}$**	ρ***
Z	Sym-bol	$g/g-atom$	$\frac{cm^2}{g}\Big/\frac{b}{atom}$	g/cm^3
21	Sc	44.956	.01340	3.02
22	Ti	47.90	.01257	4.5
23	V	50.942	.01182	5.87
24	Cr	51.996	.01158	7.14
25	Mn	54.9380	.01096	7.3
26	Fe	55.847	.01078	7.86
27	Co	58.9332	.01022	8.71
28	Ni	58.71	.01026	8.8
29	Cu	63.54	.009478	8.93
30	Zn	65.37	.009213	6.92
31	Ga	69.72	.008638	5.93
32	Ge	72.59	.008297	5.46
33	As	74.9216	.008038	5.73
34	Se	78.96	.007627	4.82
35	Br	79.909	.007537	3.12 l
36	Kr	83.80	.007187	.003743 g
37	Rb	85.47	.007046	1.53
38	Sr	87.62	.006873	2.6
39	Y	88.905	.006774	3.8
40	Zr	91.22	.006602	6.44
41	Nb	92.906	.006482	8.4
42	Mo	95.94	.006277	9.01
43	Tc	(99)	(.006083)	[11.50]
44	Ru	101.07	.005959	12.1
45	Rh	102.905	.005853	12.44
46	Pd	106.4	.005660	12.25
47	Ag	107.870	.005583	10.49
48	Cd	112.40	.005358	8.65
49	In	114.82	.005245	7.43
50	Sn	118.69	.005074	5.75–7.29
51	Sb	121.75	.004947	6.62
52	Te	127.60	.004720	6.25
53	I	126.9044	.004746	4.94
54	Xe	131.30	.004587	.005896 g
55	Cs	132.905	.004531	1.873
56	Ba	137.34	.004385	3.5
57	La	138.91	.004336	6.15
58	Ce	140.12	.004298	6.90
59	Pr	140.907	.004274	6.48
60	Nd	144.24	.004175	7.00
61	Pm	(145)	(.004153)	[7.22]******
62	Sm	150.35	.004006	7.7–7.8
63	Eu	151.96	.003963	[5.259]
64	Gd	157.25	.003830	[7.948]
65	Tb	158.924	.003790	[8.272]
66	Dy	162.50	0.003706	[8.536]
67	Ho	164.930	.003652	[8.803]
68	Er	167.26	.003601	[9.051]*****
69	Tm	168.934	.003565	[9.332]
70	Yb	173.04	.003480	[6.977]
71	Lu	174.97	.003442	[9.872]
72	Hf	178.49	.003374	13.3
73	Ta	180.948	.003328	17.1
74	W	183.85	.003276	19.3
75	Re	186.2	.003234	20.53

TABLE 1.–1. *Values of the atomic weight* M, *the factor* $(N_A/M) \times 10^{-24}$ *for converting attenuation data from b/atom to* cm^2g^{-1}, *and typical densities* ρ *for converting from* cm^2g^{-1} *to* cm^{-1}.— Continued

Element		M,* atomic wt.	$\frac{N_A}{M} \times 10^{-24}$**	ρ***
Z	Symbol	$g/g-atom$	$\frac{cm^2}{g} / \frac{b}{atom}$	g/cm^3
76	Os	190.2	.003166	22.8
77	Ir	192.2	.003133	22.42 – 22.8
78	Pt	195.09	.003087	21.4
79	Au	196.967	.003058	19.3
80	Hg	200.59	.003002	13.55 l
81	Tl	204.37	.002947	11.86
82	Pb	207.19	.002907	11.34
83	Bi	208.980	.002882	9.78
84	Po	(210)	(.002868)	[9.32]
85	At	(210)	(.002868)	....
86	Rn	(222)	(.002713)	.00996 g
87	Fr	(223)	(.002701)	....
88	Ra	(226)	(.002665)	5(?)
89	Ac	(227)	(.002653)	[10.07]
90	Th	232.038	.002595	11.00
91	Pa	(231)	(.002607)	[15.37]
92	U	238.03	.002530	18.7
93	Np	(237)	(.002541)	[19.36]
94	Pu	(242)	(.002489)	[19.84]
95	Am	(243)	(.002478)	[11.7]
96	Cm	(247)	(.002438)	[~7]
97	Bk	(249)	(.002419)	....
98	Cf	(251)	(.002399)	....
99	Es	(254)	(.002371)	....
100	Fm	(253)	(.002380)	....

*Atomic weights are those recommended in 1961 by the International Union of Pure and Applied Chemistry, based on M = 12.0000 for C^{12} (Weast and Selby [1966–1967]). These values are based on average isotopic abundances and ignore natural and artificial variations. In practice, for example, M can vary from 6.01513 for pure $_3Li^6$ to 7.01601 for pure $_3Li^7$, with a corresponding variation in the conversion factor from 0.1001 to 0.08584.

**N_A = Avogadro's number = 6.02252×10^{23} atoms/g-atom, C^{12} scale (National Academy of Sciences—National Research Council Committee on Fundamental Constants [1964]).

***Densities are for common solids, except as denoted liquid (l) or gas (g), at 20 C, from the compilation by Trent, Stone, and Lindsay [1963] and in square brackets [ ] from the Handbook of Chemistry and Physics (Hammond [1966–1967]). Gas densities are at S.T.P.: 0 °C, 76 cm Hg.

****Graphite theoretical density, based on x-ray diffraction data. Commercial-grade pile graphite, according to Loch [1960], has a density range of 1.5–1.9 g/cm³.

*****Density values for erbium vary in the literature from 4.77 as listed by Trent, Stone, and Lindsay [1963] to the values 9.05 and 9.16 given in the Handbook of Chemistry and Physics (Hammond [1966–1967]).

******The density of Pm^{147} as measured by Wheelwright [1969] is 7.22 g/cm⁻³.

Rau and Fano [1968] have examined the possible effect of irregularities in atomic shell structure on interpolation of atomic cross sections with respect to Z. Their results suggest that irregularities in the cross sections are most likely at the noble gases: He, Ne, Ar, Kr, Xe, and Rn, and at the noble metals (filling of the d-subshells): Cu, Pd and Au. At low energies ($E \lesssim 10$ keV) where the outer atomic electrons can play a significant role Manson and Cooper [1968] predict such irregularities in the photoeffect (see sec. 2.3) and Storm and Israel [1967] predict similar effects for Compton scattering (see fig. 2.–3, sec. 2.4.2.). Also Sörenssen [1965, 1966] predicts irregularities in the nuclear-field pair production cross section (see sec. 2.5.2) for energies above 100 MeV where screening of the nuclear charge by the atomic electrons becomes important. Experimental evidence for such irregularities is still inconclusive for photon energies between 10 keV and 100 MeV.

TABLE 1.–2. *Conversion factors and densities, similar to those in table* 1.–1, *for a few compounds and mixtures.*

Substance	Conversion factor	ρ
	$\frac{cm^2}{g} / \frac{b}{molecule}$	g/cm^3
H_2O	0.03344	1.00 l, 0.917 (ice)
SiO_2	.01002	2.32
NaI	.004019	3.667
Air (20 °C, 76 cm Hg)	....	0.001205 g
Concrete	....	2.2–2.4
0.8 N H_2SO_4 soln	....	1.049 l
Bone	....	1.7–2.0
Muscle	....	~1
Polystyrene, $(C_8H_8)_n$	....	1.05–1.07
Polyethylene, $(CH_2)_n$	....	0.92
Polymethyl methacrylate (Lucite), $(C_5H_8O_2)_n$	....	1.19
Bakelite (typical), $C_{43}H_{38}O_7$	....	1.20–1.70
Pyrex glass (Corning No. 7740)	....	2.23

If the absorber is a chemical compound or a mixture, its mass attenuation coefficient μ/ρ can be approximately evaluated from the coefficients μ_i/ρ_i for the constituent elements according to the weighted average

$$\mu/\rho = \sum_i w_i \mu_i/\rho_i, \qquad (1.–6)$$

where w_i is the proportion by weight of the ith constituent. For example, for water (H_2O: $M_H = 1.00797$; $M_O = 15.9994$),

$$\frac{\mu}{\rho}(H_2O) = \frac{2 \cdot 1.00797}{18.0153} \frac{\mu}{\rho}(H) + \frac{15.9994}{18.0153} \frac{\mu}{\rho}(O),$$

$$= 0.1119 \frac{\mu}{\rho}(H) + 0.8881 \frac{\mu}{\rho}(O). \qquad (1.–7)$$

Values of w_i for some additional compounds and mixtures are given in table 1.–3.

The limitations of the "mixture rule" in eq (1.–6) are that it ignores changes in the atomic wave-function resulting from changes in the molecular, chemical or crystalline environment of an atom. Above 10 keV errors from this approximation are expected to be less than a few percent (except in the fine-structure regions just above absorption edges which are most sensitive to such changes), but at very low energies (10–100 eV) errors of as much as a factor of two can occur. A survey of present knowledge of limitations of the mixture rule is given by Deslattes [1969].

Table 1.–3. *Fractions-by-weight*, w_i, *of elements in some mixtures and compounds.*
These values were used for deriving tables 3.–24 to 3.–36 from tables 3.–1 to 3.–23 according to eq (1.–6).

Element *Z*	Element Symbol	H_2O	SiO_2	NaI	Air [a]	Concrete [b]	0.8 *N* H_2SO_4 soln.[c]	Bone, compact [a]	Muscle, striated [a]	Poly-styrene, $(C_8H_8)_n$	Lucite, $(C_5H_8O_2)_n$	Poly-ethylene, $(CH_2)_n$	Bakelite,[a] $C_{45}H_{38}O_7$	Pyrex glass [d]
1	H	0.1119				0.0056	0.1084	0.064	0.102	0.0774	0.0805	0.1437	0.0574	
5	B													0.0401
6	C							.278	.123	.9226	.5999	.8563	.7746	
7	N				0.755			.027	.035					
8	O	.8881	0.5326		.232	.4983	.8791	.410	.72893		.3196		.1680	.5396
11	Na			0.1534		.0171			.0008					.0282
12	Mg					.0024		.002	.0002					
13	Al					.0456								.0116
14	Si		.4674			.3158								.3772
15	P							.070	.002					
16	S					.0012	.0125	.002	.005					
18	Ar				.013									
19	K					.0192			.003					.0033
20	Ca					.0826		.147	.00007					
26	Fe					.0122								
53	I			.8466										

[a] Composition taken from National Bureau of Standards Handbook 85 [1964].
[b] Composition assumed by White-Grodstein [1957], adjusted by McGinnies [1959] to make total = 100 percent.
[c] 3.832 percent H_2SO_4, 96.168 percent H_2O by weight, based on values in the 30th edition, p. 1635, in the Handbook of Chemistry and Physics (Hodgman [1948]). Same values, rounded off, given in the 47th edition, p. D–176 (Wolf and Brown [1966–1967]) for this range of concentration.
[d] SiO_2, 80.7 percent; B_2O_3, 12.9 percent; Na_2O, 3.8 percent; Al_2O_3, 2.2 percent; K_2O, 0.4 percent by weight. 0.2 percent has been added to SiO_2 to make total = 100 percent. Otherwise these percentages, with 80.5 percent SiO_2, are those given for Pyrex glass (Corning 7740) by Morey [1954] and also by Shand [1955].

1.4. Tabulation of Attenuation Coefficients

Table 1.–4 contains mass attenuation coefficients, μ/ρ [cm^2/g], obtained by inserting in eq (1.–5) values of $N_A/M \cdot 10^{-24}$ [(cm^{2}g^{-1})/(b/atom)] from table 1.–1 and values of σ_{tot} combined from individual cross sections quantitatively discussed in section 2. Specifically, we have used for σ_{tot} the sum

$$\sigma_{tot} \approx \tau_{pe} + \sigma_C + \kappa \qquad (1.\text{–}8)$$

of the photoelectric absorption (τ_{pe}), Compton collision (σ_C) and pair production (κ) cross sections per atom. For reasons discussed in section 2.4.2. the Rayleigh scattering cross section, σ_R, is omitted from the sum in eq (1.–8) in table 1.–4. Hence, our resulting values of μ/ρ correspond to the columns "total, without coherent (scattering)" of White-Grodstein [1957] and Davisson [1965].

Values of the attenuation coefficient including coherent scattering and the effect of electron binding on incoherent scattering are given in the tables in section 3. The relative importance of these effects is indicated in table 2.–15. The photonuclear effect has been omitted from the tables in section 3 but could be included using information in section 2.6. Values of μ/ρ extrapolated to the absorption edges can be found in the tables in section 3.

For convenience, we have reproduced in table 1.–5 the Hungerford [1960] compilation of linear attenuation coefficients, μ [cm^{-1}], at 1, 3, and 6 MeV for a number of common materials associated with shielding. With the exception of air, these values have not been revised, but agreement with table 1.–4 is within 1 to 2 percent.

Estimated uncertainties:

Due to gaps in available experimental data, and the various approximations and ranges of applicability of different theories, the accuracy of the μ/ρ entries in table 1.–4 is not the same for all values of E and Z. In the region dominated by the Compton effect, we estimate the uncertainty to be about 1 percent. Estimates of uncertainties for low-, medium- and high-Z materials are as follows:

(1) Low-Z materials:

For elements hydrogen through oxygen this 1 percent uncertainty estimate extends from 100 MeV down to about 30 keV. Below 30 keV uncertainties of as much as 5 to 10 percent may be present because of (a) poor knowledge of the photoeffect for low Z's, (b) corrections to experiments for high-Z impurities and (c) departures of the Compton cross section from Klein-Nishina theory. Above 100 MeV the contribution of the triplet cross section (see sec. 2.5.3) is increasingly important and strongly affected by screening. The theory of the triplet cross section has, except for hydrogen (Wheeler and Lamb [1939]) and for results for He by Knasel [1968], so far only been worked out with the Thomas-Fermi model of the atom. Uncertainties in μ/ρ from this source may be 5–10 percent.

(2) Medium-Z materials:

For elements sodium through copper uncertainties of 1 to 2 percent are present at low energies (10 keV to 1 MeV) because of uncertain partitioning of experimental totals into photoeffect and scattering totals. At medium energies (1 to 100 MeV) uncertainties of 2 to 3 percent are present because of uncertainties in the pair production cross section, particularly in the 10 to 30 MeV photonuclear giant resonance region. Above 100 MeV the pair production in the field of both nucleus and electrons is better-known theoretically than at lower Z. Uncertainties in μ/ρ in this region are estimated to be 1 to 2 percent.

(3) High-Z materials:

For elements molybdenum through uranium the uncertainties at low energies (10 keV to 1 MeV) range from 1 to 2 percent far from an absorption edge to 5 to 10 percent in the vicinity of an edge. In the range 1 to 100 MeV uncertainties from pair production estimates are 2 to 3 percent and above 100 MeV 1 to 2 percent.

The high-energy data from 100 MeV to 100 GeV in this report are based completely on theory. As shown in figure 1.–3, they are in general agreement with available experimental data up to 13.5 GeV.

1.5. Definition and Significance of Energy-Absorption Coefficients and Related Quantities

1.5.1. Modes of Energy Transfer

The effects of gamma rays on irradiated media are largely indirect, i.e., they occur via electrons (or positrons) which are set in motion as a result of gamma ray interactions with matter, and then dissipate their energy as they are brought to rest. The relation between electron (or positron) energy deposition in a medium and the various physical, chemical, and biological effects is complicated and, in most cases, not well understood. However, it is commonly assumed that the amount of energy absorbed per unit mass of the medium (absorbed dose) is a significant parameter which provides a basis for discussing radiation effects.

The transfer of energy from photons to electrons, and vice versa, takes place in a complex chain of events with feedbacks as indicated in the flow diagram in figure 1.–4.[8] Following this flow diagram, a complete treatment of an energy deposition problem should take into account all indicated energy transfer routes leading to electron collision losses and associated typical effects such as are listed in the bottom triangle.[9]

[8] Although the diagram in fig. 1.–4 treats electrons and positrons alike, there are actually small differences in the rates by which they lose energy (see Nelms [1956, 1958] and Berger and Seltzer [1964]).

[9] Additional energy transfer routes, not shown in fig. 1.–4, occur in the case of of nuclear absorption. The neutrons, charged particles and gamma rays resulting from such an event will, in turn, either directly or indirectly transfer additional kinetic energy to electrons. These additional routes were disregarded by R. Berger [1961], Allison [1961] and in the present work.

TABLE 1.–4. *Values of the mass attenuation coefficient μ/ρ [cm²/g], excluding Rayleigh (coherent) scattering, the effect of binding on Compton scattering, and the photonuclear effect, for a number of elements.*

That is, values here are $(\tau_{pe}+\sigma_C+\kappa_n+\kappa_e)$ b/atom $\cdot (N_A/M) \cdot 10^{-24}$[(cm²g⁻¹)/(b/atom)] using values of τ_{pe}, σ_C, κ_n and κ_e discussed in section 2 and tabulated in section 3. For coefficients extrapolated to absorption-edges, see sec. 3 tables.

PHOTON ENERGY	HYDROGEN $Z=1$	BERYLLIUM $Z=4$	BORON $Z=5$	CARBON $Z=6$	NITROGEN $Z=7$	OXYGEN $Z=8$	SODIUM $Z=11$	MAGNESIUM $Z=12$
Mev				*cm²/g*				
1.00−02	3.85−01	5.36−01	1.09+00	2.17+00	3.57+00	5.58+00	1.51+01	2.03+01
1.50−02	3.76−01	2.68−01	4.18−01	7.22−01	1.09+00	1.62+00	4.37+00	5.98+00
2.00−02	3.69−01	2.06−01	2.66−01	3.88−01	5.41−01	7.54−01	1.88+00	2.56+00
3.00−02	3.57−01	1.71−01	1.92−01	2.30−01	2.76−01	3.35−01	6.39−01	8.39−01
4.00−02	3.46−01	1.59−01	1.71−01	1.93−01	2.12−01	2.36−01	3.55−01	4.37−01
5.00−02	3.35−01	1.52−01	1.61−01	1.79−01	1.87−01	1.99−01	2.54−01	2.98−01
6.00−02	3.26−01	1.47−01	1.55−01	1.70−01	1.74−01	1.81−01	2.09−01	2.36−01
8.00−02	3.09−01	1.39−01	1.45−01	1.58−01	1.60−01	1.62−01	1.70−01	1.83−01
1.00−01	2.94−01	1.32−01	1.38−01	1.50−01	1.50−01	1.52−01	1.52−01	1.61−01
1.50−01	2.65−01	1.19−01	1.24−01	1.34−01	1.34−01	1.34−01	1.31−01	1.36−01
2.00−01	2.43−01	1.09−01	1.13−01	1.23−01	1.23−01	1.23−01	1.18−01	1.22−01
3.00−01	2.11−01	9.45−02	9.85−02	1.07−01	1.06−01	1.07−01	1.02−01	1.06−01
4.00−01	1.89−01	8.47−02	8.83−02	9.55−02	9.54−02	9.54−02	9.14−02	9.44−02
5.00−01	1.73−01	7.73−02	8.06−02	8.72−02	8.71−02	8.71−02	8.34−02	8.61−02
6.00−01	1.60−01	7.15−02	7.45−02	8.07−02	8.05−02	8.06−02	7.72−02	7.96−02
8.00−01	1.40−01	6.29−02	6.55−02	7.09−02	7.08−02	7.08−02	6.78−02	6.99−02
1.00+00	1.26−01	5.65−02	5.89−02	6.37−02	6.36−02	6.37−02	6.09−02	6.29−02
1.50+00	1.03−01	4.60−02	4.79−02	5.19−02	5.18−02	5.18−02	4.97−02	5.12−02
2.00+00	8.75−02	3.94−02	4.11−02	4.45−02	4.45−02	4.46−02	4.28−02	4.42−02
3.00+00	6.91−02	3.14−02	3.28−02	3.57−02	3.58−02	3.60−02	3.49−02	3.61−02
4.00+00	5.81−02	2.66−02	2.80−02	3.05−02	3.07−02	3.10−02	3.04−02	3.16−02
5.00+00	5.05−02	2.35−02	2.48−02	2.71−02	2.74−02	2.78−02	2.76−02	2.87−02
6.00+00	4.50−02	2.12−02	2.25−02	2.47−02	2.51−02	2.55−02	2.56−02	2.68−02
8.00+00	3.75−02	1.82−02	1.95−02	2.16−02	2.21−02	2.26−02	2.32−02	2.44−02
1.00+01	3.25−02	1.63−02	1.75−02	1.96−02	2.02−02	2.09−02	2.18−02	2.31−02
1.50+01	2.54−02	1.36−02	1.49−02	1.70−02	1.78−02	1.86−02	2.02−02	2.16−02
2.00+01	2.15−02	1.22−02	1.37−02	1.58−02	1.67−02	1.77−02	1.96−02	2.12−02
3.00+01	1.74−02	1.10−02	1.25−02	1.47−02	1.58−02	1.70−02	1.96−02	2.13−02
4.00+01	1.54−02	1.04−02	1.21−02	1.44−02	1.56−02	1.69−02	1.99−02	2.17−02
5.00+01	1.41−02	1.02−02	1.19−02	1.42−02	1.56−02	1.70−02	2.02−02	2.22−02
6.00+01	1.33−02	1.00−02	1.18−02	1.43−02	1.57−02	1.72−02	2.06−02	2.27−02
8.00+01	1.24−02	9.91−03	1.18−02	1.44−02	1.60−02	1.75−02	2.13−02	2.35−02
1.00+02	1.19−02	9.92−03	1.19−02	1.46−02	1.63−02	1.79−02	2.18−02	2.41−02
1.50+02	1.13−02	1.00−02	1.22−02	1.50−02	1.68−02	1.86−02	2.28−02	2.53−02
2.00+02	1.12−02	1.02−02	1.24−02	1.53−02	1.72−02	1.91−02	2.35−02	2.60−02
3.00+02	1.11−02	1.04−02	1.28−02	1.59−02	1.78−02	1.98−02	2.44−02	2.70−02
4.00+02	1.12−02	1.06−02	1.30−02	1.62−02	1.82−02	2.02−02	2.49−02	2.76−02
5.00+02	1.13−02	1.08−02	1.32−02	1.64−02	1.85−02	2.05−02	2.52−02	2.80−02
6.00+02	1.13−02	1.09−02	1.34−02	1.66−02	1.87−02	2.07−02	2.55−02	2.83−02
8.00+02	1.15−02	1.11−02	1.36−02	1.69−02	1.90−02	2.10−02	2.59−02	2.87−02
1.00+03	1.16−02	1.12−02	1.37−02	1.71−02	1.92−02	2.12−02	2.61−02	2.90−02
1.50+03	1.17−02	1.14−02	1.40−02	1.73−02	1.95−02	2.16−02	2.65−02	2.93−02
2.00+03	1.18−02	1.15−02	1.41−02	1.75−02	1.96−02	2.18−02	2.67−02	2.96−02
3.00+03	1.20−02	1.16−02	1.43−02	1.77−02	1.99−02	2.20−02	2.69−02	2.98−02
4.00+03	1.20−02	1.17−02	1.44−02	1.78−02	2.00−02	2.21−02	2.70−02	3.00−02
5.00+03	1.21−02	1.18−02	1.44−02	1.79−02	2.00−02	2.22−02	2.71−02	3.01−02
6.00−03	1.21−02	1.18−02	1.45−02	1.79−02	2.01−02	2.22−02	2.72− 02	3.02−02
8.00+03	1.22−02	1.19−02	1.45−02	1.80−02	2.02−02	2.23−02	2.72−02	3.02−02
1.00+04	1.22−02	1.19−02	1.46−02	1.80−02	2.02−02	2.23−02	2.73−02	3.03−02
1.50+04	1.22−02	1.19−02	1.46−02	1.81−02	2.03−02	2.24−02	2.74−02	3.03−02
2.00+04	1.23−02	1.20−02	1.47−02	1.81−02	2.03−02	2.24−02	2.74−02	3.04−02
3.00+04	1.23−02	1.20−02	1.47−02	1.82−02	2.03−02	2.25−02	2.74−02	3.04−02
4.00+04	1.23−02	1.20−02	1.47−02	1.82−02	2.03−02	2.25−02	2.75−02	3.05−02
5.00+04	1.23−02	1.20−02	1.47−02	1.82−02	2.04−02	2.25−02	2.75−02	3.05−02
6.00+04	1.23−02	1.20−02	1.47−02	1.82−02	2.04−02	2.25−02	2.75−02	3.05−02
8.00+04	1.23−02	1.20−02	1.47−02	1.82−02	2.04−02	2.25−02	2.75−02	3.05−02
1.00+05	1.23−02	1.20−02	1.47−02	1.82−02	2.04−02	2.25−02	2.75−02	3.05−02

Table 1.–4. (Continued)

PHOTON ENERGY	ALUMINUM Z=13	SILICON Z=14	PHOS-PHORUS Z=15	SULFUR Z=16	ARGON Z=18	POTASSIUM Z=19	CALCIUM Z=20	IRON Z=26
Mev				*cm²/g*				
1.00−02	2.58+01	3.36+01	4.02+01	5.03+01	6.38+01	8.01+01	9.56+01	1.72+02
1.50−02	7.66+00	9.97+00	1.20+01	1.52+01	1.95+01	2.46+01	2.96+01	5.57+01
2.00−02	3.24+00	4.19+00	5.10+00	6.42+00	8.27+00	1.05+01	1.26+01	2.51+01
3.00−02	1.03+00	1.31+00	1.55+00	1.94+00	2.48+00	3.14+00	3.82+00	7.88+00
4.00−02	5.14−01	6.35−01	7.31−01	8.91−01	1.11+00	1.39+00	1.67+00	3.46+00
5.00−02	3.34−01	3.96−01	4.44−01	5.27−01	6.30−01	7.77−01	9.25−01	1.84+00
6.00−02	2.55−01	2.92−01	3.18−01	3.67−01	4.20−01	5.12−01	5.95−01	1.13+00
8.00−02	1.89−01	2.07−01	2.15−01	2.38−01	2.52−01	2.96−01	3.34−01	5.50−01
1.00−01	1.62−01	1.73−01	1.75−01	1.89−01	1.89−01	2.16−01	2.37−01	3.42−01
1.50−01	1.34−01	1.40−01	1.38−01	1.45−01	1.36−01	1.50−01	1.59−01	1.84−01
2.00−01	1.20−01	1.25−01	1.22−01	1.27−01	1.17−01	1.28−01	1.33−01	1.39−01
3.00−01	1.03−01	1.07−01	1.04−01	1.08−01	9.79−02	1.06−01	1.09−01	1.07−01
4.00−01	9.22−02	9.54−02	9.28−02	9.58−02	8.68−02	9.38−02	9.66−02	9.21−02
5.00−01	8.41−02	8.70−02	8.46−02	8.72−02	7.90−02	8.52−02	8.78−02	8.29−02
6.00−01	7.77−02	8.05−02	7.82−02	8.06−02	7.29−02	7.87−02	8.09−02	7.62−02
8.00−01	6.83−02	7.06−02	6.86−02	7.08−02	6.40−02	6.90−02	7.09−02	6.65−02
1.00+00	6.14−02	6.35−02	6.17−02	6.36−02	5.75−02	6.20−02	6.37−02	5.96−02
1.50+00	5.00−02	5.18−02	5.03−02	5.19−02	4.69−02	5.06−02	5.20−02	4.87−02
2.00+00	4.32−02	4.48−02	4.36−02	4.49−02	4.07−02	4.39−02	4.52−02	4.25−02
3.00+00	3.54−02	3.68−02	3.59−02	3.71−02	3.38−02	3.66−02	3.78−02	3.62−02
4.00+00	3.11−02	3.24−02	3.17−02	3.29−02	3.02−02	3.28−02	3.40−02	3.31−02
5.00+00	2.84−02	2.97−02	2.92−02	3.04−02	2.80−02	3.06−02	3.17−02	3.14−02
6.00+00	2.66−02	2.79−02	2.75−02	2.87−02	2.67−02	2.91−02	3.03−02	3.05−02
8.00+00	2.44−02	2.57−02	2.55−02	2.68−02	2.51−02	2.76−02	2.89−02	2.98−02
1.00+01	2.31−02	2.46−02	2.45−02	2.58−02	2.44−02	2.70−02	2.83−02	2.98−02
1.50+01	2.19−02	2.34−02	2.36−02	2.51−02	2.41−02	2.68−02	2.83−02	3.07−02
2.00+01	2.16−02	2.33−02	2.35−02	2.52−02	2.44−02	2.73−02	2.89−02	3.21−02
3.00+01	2.19−02	2.38−02	2.42−02	2.61−02	2.55−02	2.86−02	3.05−02	3.45−02
4.00+01	2.24−02	2.45−02	2.50−02	2.70−02	2.66−02	2.99−02	3.19−02	3.65−02
5.00+01	2.30−02	2.52−02	2.57−02	2.78−02	2.75−02	3.10−02	3.31−02	3.82−02
6.00+01	2.35−02	2.57−02	2.64−02	2.86−02	2.84−02	3.19−02	3.42−02	3.95−02
8.00+01	2.44−02	2.67−02	2.74−02	2.98−02	2.96−02	3.34−02	3.58−02	4.16−02
1.00+02	2.51−02	2.75−02	2.83−02	3.07−02	3.06−02	3.45−02	3.70−02	4.32−02
1.50+02	2.63−02	2.89−02	2.98−02	3.24−02	3.25−02	3.68−02	3.94−02	4.58−02
2.00+02	2.71−02	2.99−02	3.07−02	3.34−02	3.34−02	3.77−02	4.05−02	4.75−02
3.00+02	2.82−02	3.10−02	3.19−02	3.48−02	3.48−02	3.93−02	4.22−02	4.94−02
4.00+02	2.88−02	3.17−02	3.27−02	3.56−02	3.56−02	4.02−02	4.32−02	5.06−02
5.00+02	2.92−02	3.22−02	3.32−02	3.61−02	3.61−02	4.08−02	4.38−02	5.14−02
6.00+02	2.95−02	3.25−02	3.35−02	3.65−02	3.65−02	4.12−02	4.43−02	5.19−02
8.00+02	3.00−02	3.30−02	3.40−02	3.70−02	3.71−02	4.19−02	4.50−02	5.27−02
1.00+03	3.02−02	3.33−02	3.44−02	3.74−02	3.75−02	4.23−02	4.55−02	5.32−02
1.50+03	3.07−02	3.38−02	3.48−02	3.80−02	3.80−02	4.29−02	4.61−02	5.39−02
2.00+03	3.09−02	3.41−02	3.51−02	3.83−02	3.82−02	4.32−02	4.64−02	5.43−02
3.00+03	3.12−02	3.44−02	3.54−02	3.86−02	3.86−02	4.36−02	4.68−02	5.48−02
4.00+03	3.13−02	3.45−02	3.56−02	3.88−02	3.87−02	4.38−02	4.70−02	5.50−02
5.00+03	3.14−02	3.46−02	3.57−02	3.89−02	3.89−02	4.39−02	4.72−02	5.51−02
6.00+03	3.15−02	3.47−02	3.58−02	3.90−02	3.89−02	4.40−02	4.73−02	5.52−02
8.00+03	3.16−02	3.48−02	3.59−02	3.91−02	3.91−02	4.41−02	4.74−02	5.54−02
1.00+04	3.16−02	3.48−02	3.59−02	3.91−02	3.91−02	4.42−02	4.75−02	5.55−02
1.50+04	3.17−02	3.49−02	3.60−02	3.92−02	3.92−02	4.43−02	4.76−02	5.56−02
2.00+04	3.17−02	3.50−02	3.61−02	3.93−02	3.93−02	4.43−02	4.77−02	5.56−02
3.00+04	3.18−02	3.50−02	3.61−02	3.93−02	3.93−02	4.44−02	4.77−02	5.57−02
4.00+04	3.18−02	3.51−02	3.61−02	3.94−02	3.93−02	4.45−02	4.77−02	5.57−02
5.00+04	3.18−02	3.51−02	3.62−02	3.94−02	3.93−02	4.45−02	4.78−02	5.58−02
6.00+04	3.18−02	3.51−02	3.62−02	3.94−02	3.94−02	4.45−02	4.78−02	5.58−02
8.00+04	3.18−02	3.51−02	3.62−02	3.94−02	3.94−02	4.45−02	4.78−02	5.58−02
1.00+05	3.19−02	3.51−02	3.62−02	3.94−02	3.94−02	4.45−02	4.78−02	5.58−02

Table 1.–4. (Continued)

PHOTON ENERGY	COPPER $Z=29$	MOLYB-DENUM $Z=42$	TIN $Z=50$	IODINE $Z=53$	TUNGSTEN $Z=74$	LEAD $Z=82$	URANIUM $Z=92$	ABSORPTION EDGES
Mev				cm^2/g				
1.00−02	2.23+02	8.40+01	1.39+02	1.58+02	9.12+01	1.28+02	1.73+02	
1.50−02	7.33+01	2.68+01	4.53+01	5.34+01	1.39+02	1.12+02	6.03+01	L_{III} EDGE
2.00−02	3.30+01	1.17+01	2.02+01	2.47+01	6.51+01	8.34+01	6.85+01	L_{II}, L_I EDGES
3.00−02	1.06+01	2.83+01	4.07+01	7.98+00	2.18+01	2.84+01	3.96+01	
4.00−02	4.71+00	1.30+01	1.89+01	2.23+01	9.97+00	1.31+01	1.87+01	
5.00−02	2.50+00	6.97+00	1.04+01	1.23+01	5.40+00	7.22+00	1.04+01	
6.00−02	1.52+00	4.25+00	6.32+00	7.55+00	3.28+00	4.43+00	6.45+00	
8.00−02	7.18−01	1.92+00	2.90+00	3.52+00	7.66+00	2.07+00	3.04+00	
1.00−01	4.27−01	1.05+00	1.60+00	1.91+00	4.29+00	5.23+00	1.71+00	K EDGE
1.50−01	2.08−01	3.99−01	5.77−01	6.74−01	1.50+00	1.89+00	2.47+00	
2.00−01	1.48−01	2.28−01	3.07−01	3.49−01	7.38−01	9.45−01	1.23+00	
3.00−01	1.08−01	1.31−01	1.55−01	1.68−01	3.02−01	3.83−01	4.85−01	
4.00−01	9.19−02	1.01−01	1.10−01	1.16−01	1.80−01	2.20−01	2.73−01	
5.00−01	8.22−02	8.59−02	9.11−02	9.36−02	1.29−01	1.54−01	1.85−01	
6.00−01	7.52−02	7.67−02	7.91−02	8.07−02	1.03−01	1.20−01	1.40−01	
8.00−01	6.55−02	6.52−02	6.55−02	6.61−02	7.73−02	8.56−02	9.64−02	
1.00+00	5.86−02	5.77−02	5.71−02	5.75−02	6.39−02	6.90−02	7.54−02	
1.50+00	4.79−02	4.68−02	4.59−02	4.60−02	4.88−02	5.10−02	5.39−02	
2.00+00	4.19−02	4.14−02	4.08−02	4.09−02	4.34−02	4.50−02	4.70−02	
3.00+00	3.59−02	3.66−02	3.67−02	3.69−02	4.01−02	4.16−02	4.35−02	
4.00+00	3.32−02	3.48−02	3.54−02	3.59−02	3.98−02	4.14−02	4.34−02	
5.00+00	3.18−02	3.43−02	3.53−02	3.59−02	4.06−02	4.24−02	4.44−02	
6.00+00	3.10−02	3.43−02	3.57−02	3.63−02	4.16−02	4.34−02	4.54−02	
8.00+00	3.06−02	3.50−02	3.69−02	3.78−02	4.39−02	4.59−02	4.79−02	
1.00+01	3.08−02	3.62−02	3.85−02	3.95−02	4.63−02	4.84−02	5.06−02	
1.50+01	3.23−02	3.93−02	4.25−02	4.38−02	5.24−02	5.48−02	5.73−02	
2.00+01	3.39−02	4.23−02	4.61−02	4.76−02	5.77−02	6.06−02	6.36−02	
3.00+01	3.68−02	4.70−02	5.17−02	5.36−02	6.59−02	6.96−02	7.33−02	
4.00+01	3.91−02	5.05−02	5.57−02	5.78−02	7.16−02	7.57−02	7.99−02	
5.00+01	4.10−02	5.32−02	5.88−02	6.11−02	7.60−02	8.04−02	8.50−02	
6.00+01	4.25−02	5.53−02	6.13−02	6.37−02	7.94−02	8.41−02	8.89−02	
8.00+01	4.48−02	5.86−02	6.51−02	6.76−02	8.45−02	8.96−02	9.48−02	
1.00+02	4.65−02	6.09−02	6.77−02	7.04−02	8.81−02	9.34−02	9.84−02	
1.50+02	4.94−02	6.48−02	7.21−02	7.50−02	9.39−02	9.96−02	1.06−01	
2.00+02	5.11−02	6.72−02	7.48−02	7.78−02	9.76−02	1.03−01	1.10−01	
3.00+02	5.32−02	7.00−02	7.80−02	8.11−02	1.02−01	1.08−01	1.15−01	
4.00+02	5.44−02	7.16−02	7.98−02	8.30−02	1.04−01	1.11−01	1.17−01	
5.00+02	5.52−02	7.27−02	8.10−02	8.42−02	1.06−01	1.12−01	1.19−01	
6.00+02	5.58−02	7.35−02	8.19−02	8.51−02	1.07−01	1.13−01	1.21−01	
8.00+02	5.66−02	7.45−02	8.31−02	8.64−02	1.08−01	1.15−01	1.22−01	
1.00+03	5.72−02	7.53−02	8.38−02	8.71−02	1.09−01	1.16−01	1.23−01	
1.50+03	5.79−02	7.62−02	8.49−02	8.84−02	1.11−01	1.18−01	1.25−01	
2.00+03	5.83−02	7.67−02	8.56−02	8.90−02	1.11−01	1.18−01	1.26−01	
3.00+03	5.88−02	7.73−02	8.62−02	8.96−02	1.12−01	1.19−01	1.27−01	
4.00+03	5.90−02	7.77−02	8.65−02	9.00−02	1.13−01	1.20−01	1.27−01	
5.00+03	5.91−02	7.79−02	8.67−02	9.02−02	1.13−01	1.20−01	1.28−01	
6.00+03	5.93−02	7.80−02	8.68−02	9.04−02	1.13−01	1.20−01	1.28−01	
8.00+03	5.94−02	7.81−02	8.70−02	9.05−02	1.13−01	1.20−01	1.28−01	
1.00+04	5.95−02	7.83−02	8.71−02	9.06−02	1.14−01	1.21−01	1.28−01	
1.50+04	5.96−02	7.85−02	8.73−02	9.08−02	1.14−01	1.21−01	1.29−01	
2.00+04	5.96−02	7.85−02	8.74−02	9.10−02	1.14−01	1.21−01	1.29−01	
3.00+04	5.98−02	7.86−02	8.75−02	9.11−02	1.14−01	1.21−01	1.29−01	
4.00+04	5.98−02	7.86−02	8.76−02	9.11−02	1.14−01	1.21−01	1.29−01	
5.00+04	5.98−02	7.86−02	8.77−02	9.11−02	1.14−01	1.21−01	1.29−01	
6.00+04	5.98−02	7.87−02	8.77−02	9.12−02	1.14−01	1.21−01	1.29−01	
8.00+04	5.98−02	7.88−02	8.77−02	9.12−02	1.14−01	1.21−01	1.29−01	
1.00+05	5.98−02	7.88−02	8.77−02	9.12−02	1.14−01	1.21−01	1.29−01	

TABLE 1.–5. *Gamma-ray linear attenuation coefficients* $\mu[cm^{-1}]$, for various materials of interest in shielding.

Except for slight revisions for air,[a] this is the compilation by Hungerford [1960] from data in the Hogerton-Grass Reactor Handbook [1955].

Material	Density ϱ [g/cm³]	Linear attenuation coefficient μ [cm⁻¹] 1 MeV	3 MeV	6 MeV
Air[a]) (20 °C, 76 cm Hg pressure)	0.001205	0.0000765	0.0000431	0.0000304
Aluminum	2.7	0.166	0.0953	0.0718
Ammonia (liquid)	0.771	0.0612	0.0322	0.0221
Beryllium	1.85	0.104	0.0579	0.0392
Beryllium carbide	1.9	0.112	0.0627	0.0429
Beryllium oxide (hot-pressed blocks)	2.3	0.140	0.0789	0.0552
Bismuth	9.80	0.700	0.409	0.440
Boral	2.53	0.153	0.0865	0.0678
Boron (amorphous)	2.45	0.144	0.0791	0.0679
Boron carbide (hot pressed)	2.5	0.150	0.0825	0.0675
Bricks				
Fire clay	2.05	0.129	0.0738	0.0543
Kaolin	2.1	0.132	0.0750	0.0552
Silica	1.78	0.113	0.0646	0.0473
Carbon	2.25[b])	0.143	0.0801	0.0554
Clay	2.2	0.130	0.0801	0.0590
Cements				
Colemanite borated	1.95	0.128	0.0725	0.0528
Plain (1 Portland cement: 3 sand mixture)	2.07	0.133	0.0760	0.0559
Concretes				
Barytes[c])	3.5	0.213	0.127	0.110
Barytes-boron frits[c])	3.25	0.199	0.119	0.101
Barytes-limonite[c])	3.25	0.200	0.119	0.0991
Barytes-lumnite-colemanite[c])	3.1	0.189	0.112	0.0939
Iron-Portland[c])	6.0	0.364	0.215	0.181
MO (ORNL mixture)	5.8	0.374	0.222	0.184
Portland[d]) (1 cement: 2 sand: 4 gravel mixture)	2.2	0.141	0.0805	0.0592
	2.4	0.154	0.0878	0.0646
Flesh[e])	1.0	0.0699	0.0393	0.0274
Fuel oil (medium weight)	0.89	0.0716	0.0350	0.0239
Gasoline	0.739	0.0537	0.0299	0.0203
Glass				
Borosilicate	2.23	0.141	0.0805	0.0591
Lead (Hi-D)	6.4	0.439	0.257	0.257
Plate (avg)	2.4	0.152	0.0862	0.0629
Iron	7.86	0.470	0.282	0.240
Lead	11.34	0.797	0.468	0.505
Lithium hydride (pressed powder)	0.70	0.0444	0.0239	0.0172
Lucite (polymethyl methacrylate)	1.19	0.0816	0.0457	0.0317
Paraffin	0.89	0.0646	0.0360	0.0246
Rocks				
Granite	2.45	0.155	0.0887	0.0654
Limestone	2.91	0.187	0.109	0.0824
Sandstone	2.40	0.152	0.0871	0.0641
Rubber				
Butadiene copolymer	0.915	0.0662	0.0370	0.0254
Natural	0.92	0.0652	0.0364	0.0248
Neoprene	1.23	0.0813	0.0462	0.0333
Sand	2.2	0.140	0.0825	0.0587
Type 347 stainless steel	7.8	0.462	0.279	0.236
Steel (1% carbon)	7.83	0.460	0.276	0.234
Uranium	18.7	1.46	0.813	0.881
Uranium hydride	11.5	0.903	0.504	0.542
Water	1.0	0.0706	0.0396	0.0277
Wood				
Ash	0.51	0.0345	0.0193	0.0134
Oak	0.77	0.0521	0.0293	0.0203
White pine	0.67	0.0452	0.0253	0.0175

[a] From table 3.–27.
[b] Graphite theoretical density. See table 1.–1, footnote ****.
[c] Concrete mixtures for shielding reported by Gallaher and Kitzes [1953].
[d] Elemental composition, wt %: hydrogen, 1.0; oxygen, 52.9; silicon, 33.7; aluminum, 3.4; iron, 1.4; calcium, 4.4; magnesium, 0.2; carbon, 0.1; sodium, 1.6; potassium, 1.3.
[e] Composition, wt %: oxygen, 65.99; carbon, 18.27; hydrogen, 10.15; nitrogen, 3.05; calcium, 1.52; phosphorus, 1.02.

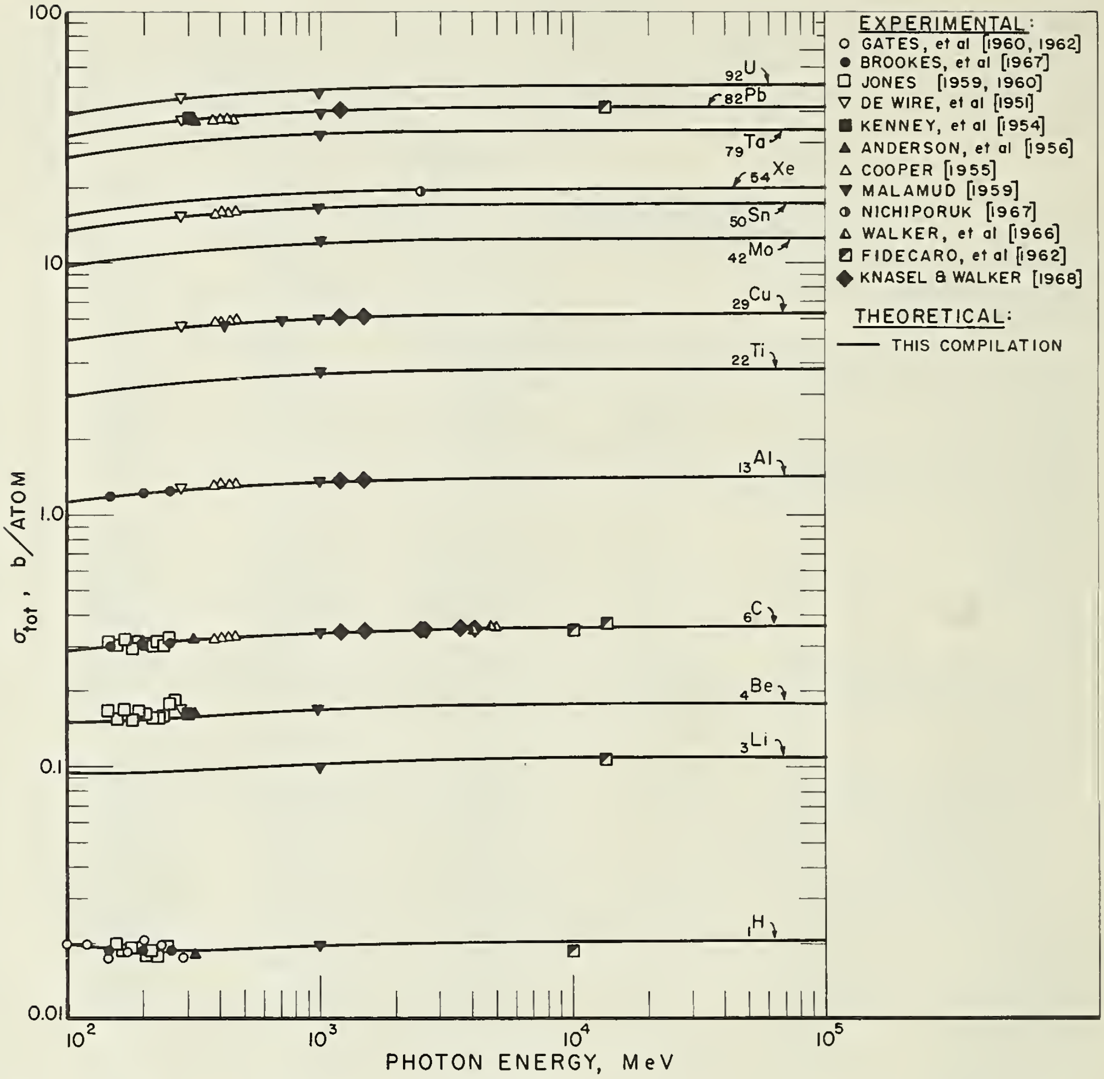

FIGURE 1.–3. *Comparison of present total cross sections* $\sigma_{\mathrm{tot}}(=\tau_{\mathrm{pe}}+\sigma_{\mathrm{C}}+\kappa_{\mathrm{n}}+\kappa_{\mathrm{e}})$ (see tables in section 3) *above 100 MeV with available experimental data.*

1.5.2. Conditions Under Which the Coefficients are Useful

At high energies the range of secondary electrons tends to become comparable with the gamma-ray mean free path, as indicated by the ratios in table 1.–6. Under such conditions the computation of gamma-ray energy deposition in a medium requires a cascade calculation involving coupled electron and photon transport equations.[10]

However, at energies below 10 MeV where the travel of electrons is of less significance, it may be sufficient to treat the problem in terms of the gamma-ray flux and either the "mass energy-absorption coefficient" or one of the various approximations such as the "mass energy-transfer coefficient" or "mass absorption coefficient" discussed in the following section 1.5.3.

[10] For a calculation of this type see, for example, that of Brysk [1954].

The amount of energy, ϵ, absorbed per unit time in a "volume of interest," ΔV, at a point $\boldsymbol{r}$ in the medium, can be expressed as the sum of two terms. The first term describes the conversion of photon energy to electron kinetic energy and involves the mass energy-absorption coefficient. The second term describes the migration of energy into and out of the volume of interest in the form of kinetic energy of electrons. Thus one can set up the energy balance equation:

$$\epsilon=\int_{\Delta V}(dr)^3\rho(\boldsymbol{r})\int_0^{E_{\max}}dE\cdot\phi(E,\boldsymbol{r})\cdot E\cdot\frac{\mu_{en}}{\rho}(E)+[\epsilon_{in}-\epsilon_{out}] \tag{1.–9}$$

in which ϵ, ϵ_{in}, and ϵ_{out} are in MeV s^{-1}, $\rho(\boldsymbol{r})$ is the density of the medium in g cm^{-3} at $\boldsymbol{r}$, E is the photon energy in MeV, and $\mu_{en}/\rho(E)$ is in cm^2 g^{-1}. The quantity $\phi(E, \boldsymbol{r})$, with dimensions MeV^{-1} cm^{-2} s^{-1}, represents the flux per unit energy interval (integrated over all directions) of photons, including secondaries, with energies between E and $E+dE$.

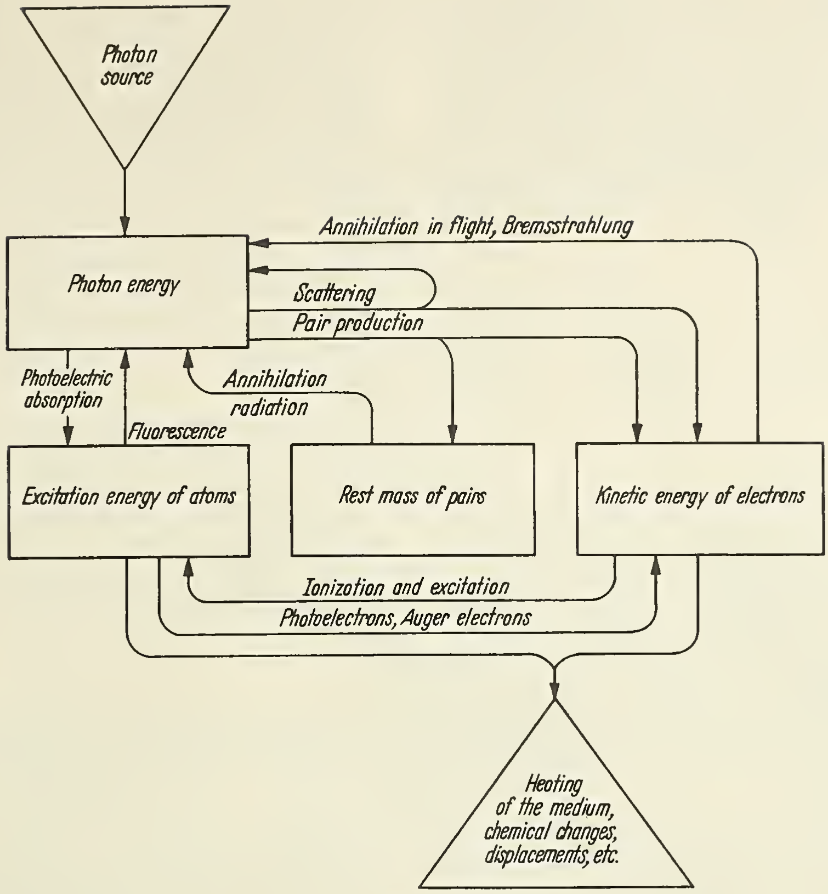

FIGURE 1.–4. *Flow diagram of conversion of energy from one form to another in the course of photon energy absorption in a medium.*

To be complete, the diagram should also contain a box labelled "excitation energy of nuclei," as well as lines representing the emission of secondary neutrons, charged particles, and gamma rays. This box has been omitted in order to prevent the diagram from becoming unduly complicated, and because the energy absorption coefficients presented here do not take into account photonuclear absorption.

TABLE 1.–6. *Ratios of the electron range,*[a] R_e, *to the photon mean-free-path,* $(1/\mu)$, *based on electron data of Berger and Seltzer [1964] and photon data from tables 1.–4 and 3.–24, –26, –27, and –28.*

Photon energy [MeV]	$_1$H	$_6$C	$_{13}$Al	$_{26}$Fe	$_{50}$Sn	$_{82}$Pb		Air	H_2O	Concrete	NaI	
						$R_e \cdot \mu$						
0.01	0.000041	0.00058	0.0091	0.076	0.087	0.11	*L*-edges *K*-edge	0.0014	0.0012	0.0074	0.085	Iodine *K*-edge
0.1	0.0020	0.0024	0.0030	0.0073	0.043	0.17		0.0025	0.0023	0.0029	0.041	
1.0	0.027	0.031	0.034	0.036	0.040	0.053		0.031	0.030	0.033	0.039	
10.0	0.077	0.11	0.13	0.18	0.23	0.29		0.11	0.11	0.12	0.22	
100.0	0.22	0.55	0.81	1.1	1.5	1.8		0.53	0.56	0.69	1.4	

a) Here we use the mean range as calculated in the continuous-slowing-down approximation.

Under conditions of electronic equilibrium,[11] $\epsilon_{in} = \epsilon_{out}$, and the second term vanishes. When the size of the volume of interest, ΔV, is large compared with the ranges of the secondary electrons involved, the term $[\epsilon_{in} - \epsilon_{out}]$ is small compared with the integral term and may be disregarded.

[11] Electronic equilibrium prevails if the gamma-ray flux distribution is effectively constant over a region having dimensions of the order of the range of the secondary electrons. Discussions of this concept and its application are given in NBS Handbook 85 [1964] and in a number of dosimetry texts (see, for example, Whyte [1959] and Johns [1961]).

1.5.3. Evaluation of the Coefficients From the Cross Sections

The "mass energy-absorption coefficient," μ_{en}/ρ, as specified in definition (17) in Appendix I of NBS Handbook 85 [1964], takes into account all the modes of energy transfer to electrons shown in figure 1.–4. The other coefficients treated here, namely the "mass energy-transfer coefficient" μ_K/ρ as specified in definition (16) in Appendix I of

NBS Handbook 85 [1964], and the "mass absorption coefficient" μ_a/ρ (sec. e.g., eq (8f–48) of Evans [1963]), are approximate and neglect some of these modes. The coefficients, μ_{en}/ρ, μ_K/ρ, and μ_a/ρ, are differently weighted sums of the probabilities per unit pathlength (in g/cm²) for photoelectric absorption (μ_τ/ρ), Compton collision (μ_C/ρ), and pair production (μ_κ/ρ):

$$\left.\begin{aligned}\mu_{en}/\rho&=\\ \mu_K/\rho&=\\ \mu_a/\rho&=\end{aligned}\right\} \left(\frac{\mu_\tau}{\rho}\right) f_\tau+\left(\frac{\mu_C}{\rho}\right) f_C+\left(\frac{\mu_\kappa}{\rho}\right) f_\kappa. \qquad (1.–10)$$

The weights f_τ, f_C, and f_κ are conversion factors which indicate, for the respective interactions, the average fraction of the photon energy which is eventually converted into kinetic energy of electrons in the volume of interest. These weights, therefore, must discount the amount of energy that escapes from the volume of interest in the form of secondary photons (which may include scattered photons, annihilation radiation, bremsstrahlung, and fluorescence radiation).

For μ_{en}/ρ the weights account for the escape of Compton-scattered, fluorescence, annihilation, and bremsstrahlung photons. For μ_K/ρ the weights account for the escape of all of these except bremsstrahlung photons. For μ_a/ρ they account for the escape of Compton-scattered photons only.

A certain part of the escaping photon radiation may also interact with the medium in the volume of interest and set electrons into motion there. This possibility is automatically taken into account if one includes in the flux $\phi(E, \mathbf{r})$ which multiplies the coefficient not only unscattered (primary) photons, but also scattered photons, and all other secondary photons, such as annihilation radiation.[12] On the other hand, the treatment must be consistent. That is, if in eq (1.–9) one uses values of μ_a/ρ or μ_K/ρ, from which the escape of certain secondary radiations is not discounted, then one should use values of $\phi(E, \mathbf{r})$ computed without considering the contributions from these radiations.

R. Berger [1961] has evaluated the coefficients f_κ, f_C, and f_τ, including all energy transfer routes shown in figure 1.–4, and from them the mass energy-absorption coefficient μ_{en}/ρ for air, water, and 15 elements and μ_K/ρ for Al, Fe, and Pb over the energy range 10 keV $\leqq E \leqq$ 10 MeV. Tabulations of μ_{en}/ρ and μ_a/ρ have been made by Allison [1961] for air, water, and seven elements over the range 10 keV $\leqq E \leqq$ 100 MeV. His procedures are essentially the same as those of Berger, with the exception that in discounting the escape of annihilation radiation he did not consider the possibility of annihilation of the positron while in flight. Thus, for heavy elements ($Z \gtrsim 26$) the Allison data are slightly different from those of Berger at energies above the pair production threshold, i.e., for $E > 1.022$ MeV. This effect of annihilation in flight amounts to ~ 2 to 3 percent at 10 MeV, and presumably more in the region $E > 10$ MeV, which was not included by Berger.

Various other authors have presented values of μ_a/ρ which, as has been discussed, discount only the energy-escape by the deflected photon in Compton scattering. Data in this approximation include the tabulations by White [1952] and Storm, Gilbert, and Israel [1958], and the graphical data of Evans [1955, 1963].

1.6. Tabulation of Energy Absorption Coefficients

In tables 1.–7 and 1.–8 we present values of μ_{en}/ρ, μ_a/ρ, and μ_K/ρ, for air, water, and 18 elements over the range 10 keV $\leqq E \leqq$ 10 MeV. These data are based on the interaction cross sections in section 2 and hence are consistent with the attenuation coefficients in table 1.–4 and in section 3.

For μ_a/ρ, values of Compton scatter losses $(1-f_C)\mu_C/\rho$ were subtracted from entries in table 1.–4. For μ_K/ρ, the compilation of fluorescence yields and average fluorescence photon energies of R. Berger [1961] was used plus values for Sn and U from Wapstra et al. [1959].[13] For μ_{en}/ρ the weights f_τ, f_C, and f_κ were taken directly or interpolated from Berger [1961], except values of f_τ for Sn and U, for which bremsstrahlung yield data from Berger and Seltzer [1964] were used.

In addition, in table 1.–9, we have excerpted the values of μ_{en}/ρ over the range 10 MeV $\leqq E \leqq$ 100 MeV from the tabulation by Allison [1961]. We also include, for comparison, values of μ_a/ρ computed from present cross sections for the same substances. As discussed in section 1.5.3, the Allison data differ from those of Berger in that positron annihilation in flight was not taken into account. However, at energies above 10 MeV the approximation involved in the use of energy-absorption or related coefficients loses some of its validity because of the comparable distances traveled by electrons and photons (see table 1.–6).

[12] Calculations of $\phi(E, \mathbf{r})$ often include only Compton scattered photons in the secondary flux (see, for example, Goldstein and Wilkins [1954]). However, for 6- to 10-MeV primary photons in lead, the annihilation photon flux has been theoretically estimated to contribute from 4 to 7 percent to $\phi(E, \mathbf{r})$ by Goldstein [1954] and by Berger, Hubbell, and Reingold [1959], and contributions of this order of magnitude have been observed experimentally by Hubbell, Hayward, and Titus [1957]. Also, theoretical estimates of the fluorescence radiation component have been made by Goldstein [1954], Veigele and Roper [1966], and Veigele and Balogh [1968].

[13] For a more recent and extensive summary of K-, L-, and M-shell fluorescence yield data, see Fink et al. [1966].

Table 1.–7. *Values of (a) the mass absorption coefficient μ_a/ρ; (b) the mass energy-transfer coefficient μ_K/ρ; and (c) the mass energy-absorption coefficient μ_{en}/ρ.*

Units are cm^2/g (see footnote a).

Photon energy [MeV]	$_1$H			$_6$C			$_7$N		
	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ
0.01	0.00991			1.98			3.38		
0.015	0.0110			0.538			0.908		
0.02	0.0136			0.208			0.362		
0.03	0.0186			0.0596			0.105		
0.04	0.0231			0.0307			0.0494		
0.05	0.0271			0.0234			0.0319		
0.06	0.0305			0.0212			0.0256		
0.08	0.0362			0.0205			0.0223		
0.10	0.0406			0.0216			0.0224		
0.15	0.0481			0.0246			0.0248		
0.2	0.0525			0.0266			0.0267		
0.3	0.0569			0.0288			0.0287		
0.4	0.0586			0.0296			0.0295		
0.5	0.0590			0.0298			0.0297		0.0296
0.6	0.0587			0.0297		0.0295	0.0296		0.0295
0.8	0.0574			0.0290		0.0288	0.0289		0.0289
1.0	0.0555			0.0280		0.0279	0.0280		0.0279
1.5	0.0507			0.0257		0.0255	0.0257		0.0255
2	0.0465		0.0464	0.0238	0.0235	0.0234	0.0238	0.0236	0.0234
3	0.0400	0.0399	0.0398	0.0210	0.0206	0.0204	0.0211	0.0207	0.0205
4	0.0355	0.0353	0.0352	0.0191	0.0187	0.0185	0.0194	0.0189	0.0186
5	0.0320	0.0319	0.0317	0.0178	0.0174	0.0171	0.0181	0.0177	0.0173
6	0.0294	0.0292	0.0290	0.0169	0.0164	0.0161	0.0172	0.0167	0.0163
8	0.0255	0.0253	0.0252	0.0156	0.0151	0.0147	0.0161	0.0156	0.0151
10	0.0229	0.0227	0.0225	0.0147	0.0143	0.0138	0.0154	0.0149	0.0143

[a]) Values for μ_K/ϱ and μ_{en}/ϱ given only if different from μ_a/ϱ.

Photon energy [MeV]	$_8$O			$_{11}$Na			$_{12}$Mg		
	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ
0.01	5.39			14.9			20.1		
0.015	1.44			4.20			5.80		
0.02	0.575			1.70			2.38		
0.03	0.165			0.475			0.671		
0.04	0.0734			0.199			0.276		
0.05	0.0438			0.106			0.144		
0.06	0.0322			0.0669			0.0888		
0.08	0.0249			0.0382			0.0475		
0.10	0.0237			0.0297			0.0346		
0.15	0.0251			0.0260			0.0279		
0.2	0.0268			0.0265			0.0277		
0.3	0.0288			0.0278			0.0288		
0.4	0.0296			0.0284			0.0294		
0.5	0.0298			0.0285			0.0294		
0.6	0.0296			0.0284			0.0293		
0.8	0.0289			0.0277		0.0275	0.0286		0.0285
1.0	0.0280		0.0278	0.0268		0.0266	0.0277		0.0275
1.5	0.0257		0.0254	0.0246	0.0245	0.0243	0.0254	0.0253	0.0251
2	0.0239	0.0236	0.0234	0.0230	0.0227	0.0225	0.0238	0.0234	0.0232
3	0.0213	0.0208	0.0206	0.0208	0.0202	0.0199	0.0216	0.0210	0.0206
4	0.0196	0.0191	0.0188	0.0195	0.0188	0.0184	0.0204	0.0196	0.0191
5	0.0185	0.0179	0.0175	0.0186	0.0179	0.0174	0.0196	0.0187	0.0181
6	0.0177	0.0171	0.0166	0.0181	0.0173	0.0167	0.0190	0.0182	0.0175
8	0.0166	0.0160	0.0155	0.0174	0.0167	0.0159	0.0185	0.0177	0.0168
10	0.0160	0.0154	0.0148	0.0171	0.0164	0.0155	0.0183	0.0176	0.0165

TABLE 1.–7 (Continued)

Photon energy [MeV]	$_{13}$Al			$_{14}$Si			$_{15}$P		
	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ
0.01	25.6	25.5	25.5	33.4	33.3	33.3	40.1	39.8	39.8
0.015	7.48	7.47	7.47	9.78	9.75	9.75	11.9	11.8	11.8
0.02	3.06			4.02	4.01	4.01	4.93	4.91	4.91
0.03	0.868			1.14	1.14	1.14	1.39	1.39	1.39
0.04	0.357			0.473	0.472	0.472	0.573	0.572	0.572
0.05	0.184			0.241			0.293		
0.06	0.111			0.144			0.173		
0.08	0.0562			0.0701			0.0820		
0.10	0.0386			0.0459			0.0511		
0.15	0.0286			0.0312			0.0323		
0.2	0.0276			0.0293			0.0292		
0.3	0.0283			0.0294			0.0288		
0.4	0.0287			0.0298			0.0291		
0.5	0.0288		0.0286	0.0298			0.0290		
0.6	0.0286		0.0286	0.0296		0.0295	0.0288		
0.8	0.0279		0.0277	0.0289		0.0288	0.0281		0.0278
1.0	0.0270		0.0269	0.0279		0.0277	0.0272		0.0270
1.5	0.0248	0.0247	0.0245	0.0257	0.0255	0.0253	0.0250	0.0248	0.0246
2	0.0233	0.0229	0.0226	0.0241	0.0237	0.0234	0.0235	0.0231	0.0228
3	0.0213	0.0206	0.0202	0.0221	0.0214	0.0210	0.0217	0.0209	0.0204
4	0.0201	0.0193	0.0188	0.0211	0.0202	0.0196	0.0207	0.0198	0.0192
5	0.0194	0.0185	0.0179	0.0204	0.0194	0.0187	0.0201	0.0191	0.0184
6	0.0190	0.0181	0.0172	0.0201	0.0191	0.0182	0.0198	0.0188	0.0179
8	0.0186	0.0177	0.0168	0.0197	0.0187	0.0177	0.0197	0.0187	0.0175
10	0.0185	0.0176	0.0165	0.0197	0.0188	0.0175	0.0197	0.0188	0.0174

Photon energy [MeV]	$_{16}$S			$_{18}$Ar			$_{19}$K		
	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ
0.01	50.1	49.7	49.7	63.6	62.3	62.3	79.9	77.6	77.6
0.015	15.0	14.9	14.9	19.3	19.1	19.1	24.4	23.9	23.9
0.02	6.24	6.21	6.21	8.10	8.02	8.02	10.3	10.2	10.2
0.03	1.77	1.77	1.77	2.33	2.31	2.31	2.97	2.94	2.94
0.04	0.729	0.727	0.727	0.967	0.962	0.962	1.23	1.23	1.23
0.05	0.372			0.490	0.488	0.488	0.626	0.623	0.623
0.06	0.218			0.285	0.284	0.284	0.368	0.366	0.366
0.08	0.101			0.128			0.162	0.162	0.162
0.10	0.0610			0.0735			0.0915	0.0913	0.0913
0.15	0.0357			0.0377			0.0442		
0.2	0.0311			0.0304			0.0343		
0.3	0.0300			0.0278			0.0304		
0.4	0.0301			0.0275			0.0298		
0.5	0.0300			0.0273			0.0295		0.0293
0.6	0.0298			0.0270		0.0268	0.0292		0.0290
0.8	0.0290		0.0288	0.0262		0.0261	0.0283		0.0282
1.0	0.0280		0.0278	0.0253		0.0251	0.0273		0.0270
1.5	0.0258	0.0256	0.0253	0.0233	0.0232	0.0229	0.0252	0.0250	0.0247
2	0.0243	0.0238	0.0235	0.0220	0.0215	0.0212	0.0238	0.0233	0.0229
3	0.0225	0.0216	0.0211	0.0206	0.0198	0.0192	0.0224	0.0214	0.0208
4	0.0216	0.0205	0.0199	0.0199	0.0189	0.0182	0.0218	0.0206	0.0198
5	0.0211	0.0200	0.0192	0.0197	0.0185	0.0177	0.0215	0.0202	0.0193
6	0.0209	0.0197	0.0188	0.0196	0.0184	0.0174	0.0215	0.0202	0.0190
8	0.0208	0.0197	0.0184	0.0197	0.0186	0.0173	0.0218	0.0205	0.0190
10	0.0210	0.0200	0.0184	0.0201	0.0190	0.0174	0.0222	0.0210	0.0191

TABLE 1.–7 (Continued)

Photon energy [MeV]	$_{20}$Ca			$_{26}$Fe			$_{29}$Cu		
	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ
0.01	95.4	91.6	91.6	171.	142.	142.	223.	160.	160.
0.015	29.4	28.6	28.6	55.5	49.3	49.3	73.2	59.4	59.4
0.02	12.4	12.2	12.2	24.9	22.8	22.8	32.8	28.2	28.2
0.03	3.65	3.60	3.60	7.72	7.28	7.28	10.5	9.50	9.50
0.04	1.51	1.50	1.50	3.31	3.17	3.17	4.56	4.24	4.24
0.05	0.770	0.764	0.764	1.69	1.64	1.64	2.35	2.22	2.22
0.06	0.447	0.444	0.444	0.989	0.961	0.961	1.39	1.32	1.32
0.08	0.197	0.196	0.196	0.422	0.414	0.414	0.593	0.573	0.573
0.10	0.109			0.223	0.219	0.219	0.311	0.302	0.302
0.15	0.0498			0.0821	0.0814	0.0814	0.108	0.106	0.106
0.2	0.0371			0.0498	0.0495	0.0495	0.0602	0.0597	0.0597
0.3	0.0318			0.0342	0.0335	0.0335	0.0371	0.0370	0.0370
0.4	0.0309			0.0308			0.0318		
0.5	0.0304			0.0295			0.0298		
0.6	0.0300		0.0299	0.0287		0.0286	0.0287		0.0286
0.8	0.0291		0.0289	0.0275		0.0273	0.0273	0.0272	0.0271
1.0	0.0281	0.0280	0.0278	0.0264		0.0262	0.0261	0.0261	0.0258
1.5	0.0259	0.0257	0.0254	0.0243	0.0241	0.0237	0.0240	0.0237	0.0233
2	0.0245	0.0240	0.0236	0.0233	0.0225	0.0220	0.0230	0.0222	0.0217
3	0.0231	0.0220	0.0214	0.0225	0.0212	0.0204	0.0225	0.0211	0.0202
4	0.0226	0.0213	0.0205	0.0225	0.0209	0.0199	0.0228	0.0211	0.0200
5	0.0224	0.0211	0.0200	0.0228	0.0211	0.0198	0.0233	0.0214	0.0200
6	0.0225	0.0211	0.0198	0.0232	0.0215	0.0199	0.0239	0.0220	0.0202
8	0.0229	0.0215	0.0198	0.0242	0.0226	0.0204	0.0251	0.0234	0.0209
10	0.0234	0.0222	0.0201	0.0252	0.0238	0.0209	0.0264	0.0248	0.0215

Photon energy [MeV]	$_{50}$Sn			$_{82}$Pb			$_{92}$U		
	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_K/ϱ	μ_{en}/ϱ
0.01	139.	136.	136.	128.	127.	127.	173.	171.	170.
0.015	45.2	43.7	43.6	112.0	91.7	91.7	60.2	59.6	59.4 L_{III}
0.02	20.0	19.8	19.8	83.3	69.2	69.1	68.3	55.5	55.5 $L_{II,I}$
0.03	40.5	16.2	16.2	28.2	24.6	24.6	39.4	33.0	33.0
0.04	18.8	9.97	9.96	13.0	11.8	11.8	18.6	16.3	16.3
0.05	10.2	6.25	6.24	7 10	6.57	6.54	10.3	9.30	9.25
0.06	6.20	4.20	4.19	4.31	4.11	4.08	6.34	5.82	5.78
0.08	2.78	2.19	2.18	1.96	1.87	1.86	2.94	2.76	2.73
0.10	1.49	1.26	1.25	5.12	2.28	2.28	1.61	1.54	1.52 K
0.15	0.485	0.446	0.442	1.80	1.16	1.15	2.39	1.12	1.19
0.2	0.226	0.211	0.209	0.869	0.637	0.629	1.15	0.712	0.704
0.3	0.0892	0.0853	0.0843	0.322	0.265	0.259	0.425	0.322	0.315
0.4	0.0550	0.0536	0.0530	0.168	0.147	0.143	0.222	0.184	0.178
0.5	0.0428	0.0423	0.0416	0.108	0.0984	0.0951	0.140	0.122	0.118
0.6	0.0361	0.0358	0.0353	0.0793	0.0737	0.0710	0.100	0.0902	0.0864
0.8	0.0302	0.0301	0.0294	0.0525	0.0503	0.0481	0.0640	0.0599	0.0569
1.0	0.0271	0.0270	0.0264	0.0407	0.0396	0.0377	0.0479	0.0458	0.0432
1.5	0.0239	0.0233	0.0226	0.0303	0.0288	0.0271	0.0337	0.0317	0.0295
2	0.0234	0.0220	0.0210	0.0286	0.0259	0.0240	0.0310	0.0278	0.0255
3	0.0243	0.0219	0.0205	0.0300	0.0260	0.0234	0.0322	0.0276	0.0246
4	0.0259	0.0232	0.0212	0.0324	0.0281	0.0245	0.0346	0.0298	0.0256
5	0.0275	0.0247	0.0221	0.0350	0.0306	0.0259	0.0372	0.0324	0.0270
6	0.0290	0.0262	0.0230	0.0372	0.0331	0.0272	0.0394	0.0348	0.0281
8	0.0319	0.0292	0.0245	0.0411	0.0378	0.0294	0.0433	0.0392	0.0298
10	0.0344	0.0319	0.0258	0.0446	0.0419	0.0310	0.0468	0.0432	0.0312

Table 1.-7 (Continued)

Photon energy [MeV]	Air μ_a/ϱ	Air μ_K/ϱ	Air μ_{en}/ϱ	H_2O μ_a/ϱ	H_2O μ_K/ϱ	H_2O μ_{en}/ϱ
0.01	4.63	4.61	4.61	4.79		
0.015	1.27	1.27	1.27	1.28		
0.02	0.512	0.511	0.511	0.512		
0.03	0.148			0.149		
0.04	0.0669			0.0678		
0.05	0.0406			0.0419		
0.06	0.0305			0.0320		
0.08	0.0243			0.0262		
0.10	0.0234			0.0256		
0.15	0.0250			0.0277		
0.2	0.0268			0.0297		
0.3	0.0288			0.0319		
0.4	0.0295			0.0328		
0.5	0.0297		0.0296	0.0330		
0.6	0.0296		0.0295	0.0329		
0.8	0.0289		0.0289	0.0321		
1.0	0.0280		0.0278	0.0311		0.0309
1.5	0.0257		0.0254	0.0285		0.0282
2	0.0238	0.0236	0.0234	0.0264	0.0262	0.0260
3	0.0212	0.0207	0.0205	0.0234	0.0229	0.0227
4	0.0194	0.0189	0.0186	0.0214	0.0209	0.0206
5	0.0182	0.0178	0.0174	0.0200	0.0195	0.0191
6	0.0174	0.0168	0.0164	0.0190	0.0185	0.0180
8	0.0162	0.0157	0.0152	0.0176	0.0170	0.0166
10	0.0156	0.0151	0.0145	0.0168	0.0162	0.0157

Table 1.-8. *Values of μ_a/ρ, μ_K/ρ, and μ_{en}/ρ extrapolated to the absorption edges from the low-energy and high-energy sides, respectively. Units are cm^2/g.*

Absorption edge	$_{50}Sn$ [keV]	μ_a/ρ	μ_K/ρ	μ_{en}/ρ	$_{82}Pb$ [keV]	μ_a/ρ	μ_K/ρ	μ_{en}/ρ	$_{92}U$ [keV]	μ_a/ρ	μ_K/ρ	μ_{en}/ρ
L_{III}					13.041	63.9	63.5	63.3	17.165	42.6	42.2	42.1
						162.	129.	129.		103.	80.1	80.1
L_{II}					15.205	109.	89.6	89.6	20.945	60.2	49.4	49.4
						142.	113	113.		85.5	66.9	66.9
L_I					15.855	126.	102.	102.	21.771	77.4	61.2	61.1
						154.	123.	123.		89.4	69.6	69.6
K	29.195	6.74	6.70	6.69	88.005	1.51	1.45	1.44	115.62	1.09	1.05	1.04
		43.5	16.7	16.7		7.12	2.47	2.47		4.62	1.66	1.66

TABLE 1.–9. *Values of the mass absorption coefficient μ_a/ρ and mass energy-absorption coefficient* [a] *μ_{en}/ρ for photon energies 10 to 100 MeV.*

Units are cm²/g.

Photon energy [MeV]	$_1$H		$_7$N		$_8$O		$_{13}$Al		$_{18}$Ar	
	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ
10	0.0229	0.0222	0.0154	0.0143	0.0160	0.0148	0.0185	0.0164	0.0201	0.0176
15	0.0188	0.0179	0,0145	0.0131	0.0153	0.0136	0.0187	0.0163	0.0211	0.0183
20	0.0166	0.0156	0.0142	0.0128	0.0152	0.0135	0.0192	0.0162	0.0222	0.0187
30	0.0141	0.0130	0.0142	0.0123	0.0153	0.0131	0.0203	0.0164	0.0240	0.0192
40	0.0129	0.0116	0.0144	0.0121	0.0156	0.0130	0.0212	0.0166	0.0254	0.0192
50	0.0121	0.0107	0.0146	0.0119	0.0160	0.0129	0.0220	0.0164	0.0266	0.0192
60	0.0117	0.0102	0.0149	0.0118	0.0163	0.0129	0.0227	0.0161	0.0276	0.0190
80	0.0111	0.0095	0.0153	0.0118	0.0169	0.0127	0.0238	0.0159	0.0290	0.0188
100	0.0109	0.0092	0.0158	0.0119	0.0174	0.0127	0.0246	0.0156	0.0301	0.0184

Photon energy [MeV]	$_{26}$Fe		$_{82}$Pb		Air		Water	
	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ	μ_a/ϱ	μ_{en}/ϱ
10	0.0252	0.0212	0.0446	0.0324	0.0156	0.0145	0.0168	0.0155
15	0.0277	0.0223	0.0522	0.0352	0.0148	0.0132	0.0157	0.0141
20	0.0298	0.0230	0.0587	0.0367	0.0145	0.0131	0.0153	0.0136
30	0.0330	0.0236	0.0682	0.0375	0.0146	0.0126	0.0152	0.0131
40	0.0354	0.0235	0.0747	0.0372	0.0148	0.0124	0.0153	0.0128
50	0.0372	0.0234	0.0796	0.0366	0.0151	0.0122	0.0156	0.0126
60	0.0387	0.0230	0.0834	0.0357	0.0154	0.0122	0.0158	0.0125
80	0.0410	0.0233	0.0890	0.0334	0.0159	0.0121	0.0163	0.0125
100	0.0427	0.0217	0.0930	0.0301	0.0163	0.0121	0.0167	0.0124

[a] Values of μ_{en}/ρ in this table are taken directly from Allison [1961]. Hence the input cross-section data are those of White-Grodstein [1957], and positron annihilation in flight is not taken into account.

2. Photon Cross Sections

2.1. Scope

This section contains descriptions and tabulations of the individual atomic cross sections for scattering, absorption, and pair production that enter into the computation of the attenuation, energy absorption, and other related coefficients. The information in this report is confined primarily to total cross sections, although some angular distribution information for Compton and Rayleigh scattering is included.[14]

2.2. Classification of Interactions

Interactions of photons with matter, by which individual photons are removed or deflected from a primary beam of x- or γ-radiation, may be classified according to:

(1) The kind of target, e.g., electrons, atoms, or nuclei, with which the photon interacts, and
(2) The type of event, e.g., scattering, absorption, pair production, etc., which takes place.

Possible interactions are summarized in table 2.–1 (adapted from Fano, Spencer, and Berger [1959]). The relative magnitudes of cross sections for these interactions as functions of energy are shown in figure 2.–1, in which the vertical distance between curves represents the percent contribution of an indicated cross section to the total "electronic" cross section (i.e., excluding photo-nuclear effects).

It is apparent from figure 2.–1 that for attenuations of photons in this energy range the most important interactions are:

(1) The photoelectric effect, τ_{pe},
(2) Compton scattering, σ_C, and
(3) Electron-positron pair production, $(\kappa_n + \kappa_e)$.

Rayleigh scattering, σ_R, is usually of minor importance for the broad beam conditions typically found in shielding but must be known for interpretation of experimental attenuation coefficient data. Two-photon Compton scattering, together with the radiative correction, amounts to less than 1 percent of σ_C below 100 MeV and is included in the total Compton cross section σ_C in figure 2.–1. The photonuclear effect, $\sigma_{ph.n.}$, is mostly restricted to the region of the giant resonance around 10 to 30 MeV where, at the resonance peak, it may amount to as much as 10 percent of the total "electronic" cross section.

[14] For further angular distribution data and formulas, reference for Compton scattering can be made to Compton and Allison [1935], Davisson and Evans [1952], Nelms [1953], Burton [1953], Evans [1958], Curien [1962], Stinner et al. [1965], and Veigele [1965]; for the atomic photoeffect to Hultberg et al. [1968] and Pratt et al. [1964]; and for electron-positron pair production to Heitler [1954].

TABLE 2.–1. *Classification of elementary photon interactions.*

Solid-line boxes indicate the major effects contributing to photon attenuation in matter. Dotted-line boxes indicate additional effects which contribute more than 1 percent over particular energy ranges.

Type of interaction / Interaction with:	Absorption (a)	Scattering: Elastic (coherent) (b)	Scattering: Inelastic (incoherent) (c)	Multi-photon effects (d)
(1) Atomic electrons	Photoelectric effect $\tau_{pe}\begin{cases}\sim Z^4 \text{ (low energy)}\\ \sim Z^5 \text{ (high energy)}\end{cases}$	Rayleigh scattering, $\sigma_R \sim Z^2$ (low energy limit	Compton scattering, $\sigma_C \sim Z$	Two-photon Compton scattering, $\sim Z$
(2) Nucleons	Photonuclear reactions (γ, n), (γ, p), photo-fission, etc. $\sigma_{ph.n.} \sim Z$ $(E \gtrsim 10 \text{ MeV})$	Elastic nuclear scattering, $(\gamma, \gamma) \sim Z^2$	Inelastic nuclear scattering, (γ, γ')	
(3) Electric field surrounding charged particles	(1) Electron-positron pair production in field of nucleus, $\varkappa_n \sim Z^2$ $(E \geqq 1.02 \text{ MeV})$ (2) Electron-positron pair production in electron field, $\varkappa_e \sim Z$ $(E \geqq 2.04 \text{ MeV})$ (3) Nucleon-antinucleon pair production $(E \gtrsim 3 \text{ GeV})$	Delbrück scattering, $\sim Z^4$		
(4) Mesons	Photomeson production, $(E \gtrsim 150 \text{ MeV})$	Modified (γ, γ)		

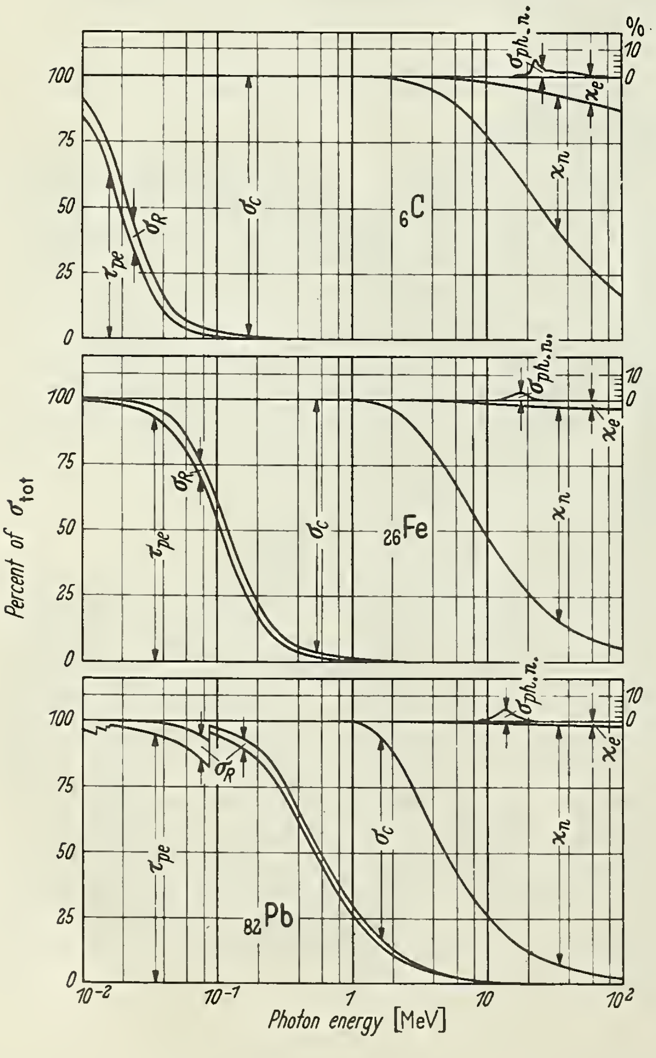

FIGURE 2.–1. *Relative contributions of the various photon interactions as functions of energy for carbon, iron, and lead.*

In these plots the vertical distance *between* curves represents the percent contribution of the indicated process to the sum $\tau_{pe}+\sigma_R+\sigma_C+\kappa_n+\kappa_e$ (see tables in section 3).

The remaining small effects (resonance scattering and Thomson scattering by the nucleus, Compton scattering by nucleons, meson production, resonance scattering associated with meson production, Delbrück scattering and nucleon-antinucleon production) will not be treated here. For a general discussion of these effects, including order of magnitude estimates, see Bethe and Ashkin [1953]. Recent photomeson data have been summarized by Crouch et al. [1964], Allaby et al. [1966], Panofsky [1968], and Joos [1968]. We have reproduced in table 2.–2 the photomeson cross section compilation by E. Lohrmann in the review by Joos [1968].

TABLE 2.–2. *Meson photoproduction cross sections in $\mu b (10^{-30} cm^2)$, as summarized by E. Lohrmann in the article by Joos [1968].*

Reaction $\gamma P \rightarrow$	Photon energy				References
	1 GeV	2 GeV	3 GeV	4.5 GeV	
$p\pi^{\circ}$	24	4.7	1.5	0.6	70, 71, 72, 74
$n\pi^{\circ}$	50	5	2.2	1.0	70, 72, 73, 75, 76
$P\rho^{\circ}$	....	20	17	17	45, 47, 52, 55
$P\omega$	....	7	4	3	46, 51, 55
$P\phi$	....	~ 0.2	~ 0.3	~ 0.2	55
$P\eta$	6	<1	<1	<0.2	51, 55, 78, 79, 80
$PX^{\circ}(959)$	....	~ 0.7	~ 0.2	~ 0.2	51, 55
Pf°	....	....	~ 0.9	~ 0.3	52, 55
$\Delta^{++}(1238)\pi^{-}$	48	8	4	2	50, 55, 77, 81, 82
$\Delta^{\circ}\pi^{+}$	2	....	....	....	55, 77
$\Delta^{++}\rho^{-}$	....	~ 4	~ 2	~ 1	52, 55, 77
ΛK^{+}	2	~ 1	~ 0.5	~ 0.25	53, 73, 83, 84
$\Sigma^{\circ}K^{+}$	....	~ 0.6	~ 0.2	~ 0.1	53, 73
$\Sigma^{+}K^{\circ}$	....	<0.2	<0.2	<0.2	53
$Y^{*\circ}(1385)K^{+}$	....	~ 0.5		~ 0.2	53
$Y^{*+}(1385)K^{\circ}$	....	~ 0.4		~ 0.1	53

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The cross section for photoproduction of nucleon-antinucleon pairs, as discussed by Vdovin [1957], Bushev and Vdovin [1958], Segré [1958], Bertram et al. [1966], and Earles et al. [1967], is three orders of magnitude smaller than that for photomeson production. The threshold for nucleon-antinucleon pair production varies from 3.75 GeV (4 nucleon masses) in the field of a proton at rest down to 3.0 GeV (3.2 nucleon masses) for protons moving in a complex nucleus.

2.3. Atomic Photoeffect (Photoelectric Absorption)

In the atomic photoeffect, a photon disappears and an electron is ejected from an atom. The electron carries away all the energy of the absorbed photon, minus the energy binding the electron to the atom. The *K*-shell electrons, which are the most tightly bound, are the most important for this effect in the energy region considered in this report. However, if the photon energy drops below the binding energy of a given shell (see table 2.–3), an electron from that shell cannot be ejected. Hence, a plot of τ_{pe} versus photon energy exhibits the characteristic "absorption edges"[15] which are shown for lead in figure 2.–1.

Although there have been a few direct measurements of τ_{pe} or τ_K in the region between 0.1 and 3 MeV (see, for example, Latyshev [1947], Seeman [1956], Hultberg and Stockendal [1959], Titus [1959, 1965], Bleeker, Goudsmit, and DeVries [1962], Dowe [1965], and Parthasaradhi et al. [1966]), the best information in the high energy region is at present mostly theoretical.

Most of the theoretical information has been on the *K*-shell component τ_K (see, for example, Bethe and Salpeter [1957], Erber [1959], Gavrila [1959], Pratt [1960a], Nagel [1960], Hultberg et al. [1961],

[15] As a note of caution, it should be mentioned that the high-energy side of an absorption edge exhibits a fine structure (see, for example, Faessler [1955], Sandström [1957], or Azároff [1963]) such that for light elements, where the *K*-edge is well below 10 keV, τ_{pe} can oscillate by as much as a factor of five near the edge. However, for the region above 10 keV considered here, the oscillation is less than 10 percent and will be disregarded, for practical purposes, in favor of a smooth extrapolation from the monotonic region back to the theoretical edge.

TABLE 2.–3. *Energies of absorption edges above* 10 *keV.*
Values are taken from Bearden [1964–1967] except numbers in parentheses, which are from Fine and Hendee [1955].

Element	*K*-edge [keV]	Element	*K*-edge [keV]	L_I - edge [keV]	L_{II} - edge [keV]	L_{III} - edge [keV]
$_{31}$Ga	10.368	$_{66}$Dy	53.793			
$_{32}$Ge	11.104	$_{67}$Ho	55.619			
$_{33}$As	11.865	$_{68}$Er	57.487			
$_{34}$Se	12.654	$_{69}$Tm	59.38	10.121		
$_{35}$Br	13.470	$_{70}$Yb	61.30	10.490		
$_{36}$Kr	14.324	$_{71}$Lu	63.31	10.874	10.345	
$_{37}$Rb	15.202	$_{72}$Hf	65.31	11.274	10.736	
$_{38}$Sr	16.107	$_{73}$Ta	67.403	11.682	11.132	
$_{39}$Y	17.038	$_{74}$W	69.508	12.100	11.538	10.200
$_{40}$Zr	17.999	$_{75}$Re	71.658	12.530	11.954	10.531
$_{41}$Nb	18.987	$_{76}$Os	73.856	12.972	12.381	10.868
$_{42}$Mo	20.004	$_{77}$Ir	76.101	13.423	12.820	11.212
$_{43}$Te	21.047	$_{78}$Pt	78.381	13.883	13.272	11.562
$_{44}$Ru	22.119	$_{79}$Au	80.720	14.354	13.736	11.921
$_{45}$Rh	23.219	$_{80}$Hg	83.109	14.842	14.212	12.286
$_{46}$Pd	24.348	$_{81}$Tl	85.533	15.343	14.699	12.660
$_{47}$Ag	25.517	$_{82}$Pb	88.005	15.855	15.205	13.041
$_{48}$Cd	26.716	$_{83}$Bi	90.534	16.376	15.719	13.426
$_{49}$In	27.942	$_{84}$Po	(93.112)	(16.935)	(16.244)	(13.817)
$_{50}$Sn	29.195	$_{85}$At	(95.740)	(17.490)	(16.784)	(14.215)
$_{51}$Sb	30.486	$_{86}$Rn	(98.418)	(18.058)	(17.337)	(14.618)
$_{52}$Te	31.811	$_{87}$Fr	(101.147)	(18.638)	(17.904)	(15.028)
$_{53}$I	33.166	$_{88}$Ra	(103.927)	19.236	18.486	15.444
$_{54}$Xe	34.59	$_{89}$Ac	(106.759)	(19.842)	(19.078)	(15.865)
$_{55}$Cs	35.987	$_{90}$Th	109.646	20.464	19.683	16.299
$_{56}$Ba	37.452	$_{91}$Pa	(112.581)	(21.102)	(20.311)	(16.731)
$_{57}$La	38.934	$_{92}$U	115.62	21.771	20.945	17.165
$_{58}$Ce	40.453	$_{93}$Np	(118.619)	(21.417)	(20.596)	(17.614)
$_{59}$Pr	42.002	$_{94}$Pu	(121.720)	23.109	22.253	18.054
$_{60}$Nd	43.574	$_{95}$Am	(124.876)	(23.793)	(22.944)	(18.525)
$_{61}$Pm	45.198	$_{96}$Cm	(128.088)	(24.503)	(23.640)	(18.990)
$_{62}$Sm	46.849	$_{97}$Bk	(131.357)	(25.230)	(24.352)	(19.461)
$_{63}$Eu	48.519	$_{98}$Cf	(134.683)	(25.971)	(25.080)	(19.938)
$_{64}$Gd	50.233	$_{99}$E	(138.067)	(26.729)	(25.824)	(20.422)
$_{65}$Tb	52.002	$_{100}$Fm	(141.510)	(27.503)	(26.584)	(20.912)

Pratt et al. [1964], Hall and Sullivan [1966], Gorshkov [1967], Forssner [1968], and Hultberg et al. [1968]), but some calculations including L- and higher-shell contributions are now available (see, for example, Pratt [1960b], Gavrila [1961], Alling and Johnson [1965], Matese and Johnson [1965], Schmickley and Pratt [1967], Brysk and Zerby [1968], and the extensive results by Rakavy and Ron [1967] which include almost all the higher shells and cover the range 1 keV to 2 MeV). Uncertainties in τ_K due to screening and other effects are probably about 2 percent over the region from 0.2 to 100 MeV. However, the uncertainty of the total $\tau_{pe}(=\tau_K+\tau_L+\tau_M+\cdot\cdot\cdot)$ is probably more like 3 to 5 percent because of much poorer knowledge of the outer shell contribution, which amounts to as much as $\frac{1}{4}$ of τ_K for the heavier elements.

Extensive theoretical results for the photoeffect in the soft x-ray region (0.1 to 2 keV) are now becoming available (Cooper [1962, 1964], Fano and Cooper [1965], Manson and Cooper [1968], and Fano and Cooper [1968]). The work of these authors is based on the solution of the Schrödinger equation in the dipole approximation, using self-consistent-field wave functions. Numerical results are given for the photoelectric absorption in various outer atomic subshells, with emphasis on the detailed structure of the cross section near threshold. These papers also provide a survey of recent experimental results in the soft x-ray region obtained with synchrotron light and other soft x-ray sources.

In the energy range 10 keV to 0.2 MeV, although the Rakavy-Ron calculations are in considerably better agreement with experiments than are previous theoretical results, present estimates of τ_{pe} in this region still rely heavily on high-precision total attenuation coefficient measurements such as those of Hahn [1934], Cuykendall [1936], Jones [1936], Laubert [1941], Bearden [1958, 1966], Deslattes [1958], Wiedenbeck [1962]; McCrary, Plassmann et al. [1967], and others.

From these measurements "experimental" values of τ_{pe} are obtained by subtracting theoretical estimates of the scattering cross sections $\sigma_C^{BD}+\sigma_R$ from the observed values of σ_{tot}.

In the present tabulation in the region 10 keV $\leqq E \lesssim 100$ keV, we follow the subtraction procedure, using re-evaluated experimental σ_{tot} data and scattering cross sections $(\sigma_C^{BD}+\sigma_R)$ from Storm and Israel [1967], except for uranium for which τ_{pe} is taken directly from Rakavy and Ron. Values of τ_{pe} for tin, tungsten and lead in this energy were taken from a computer-assisted subtraction and analysis in progress (McMaster, Del Grande et al.) and hence constitute a further updating of τ_{pe}, σ_{tot} and related quantities from values given by Hubbell and Berger [1968].

At higher energies we present revised values for τ_{pe} which take into account not only the numerical calculations of τ_K by Pratt et al. [1964] used by Davisson, but also the extensive τ_K calculations by Hultberg et al. [1968]. Although we use the results of Gavrila [1959] and Pratt [1960a] in the high energy limit, we ignore, on the advice of Pratt, the extrapolated values of τ_K in table 2 in Pratt [1960a] for $Z/137=0.4$ and 0.6 at energies $E=2$, 3, 5 and 10 MeV.

As can be seen in table 2.–4, τ_{pe} varies over a wide range of magnitudes, decreasing with increasing energy except at the edges and increasing with atomic number. To make interpolation more reliable and convenient, it is important to scale these values in some way. It was found that the product $\tau_{pe}\cdot(E[\text{MeV}])^3\cdot Z^{-4.5}$ (above or between absorption edges) varies by less than a factor of three over the range $Z=1$ to 92 and E = 10 to 500 keV, and the product $\tau_{pe}\cdot E[\text{MeV}]\cdot Z^{-4.5}$ by less than a factor of ten for $Z=1$ to 92 and $E=500$ keV to 100 MeV. Values of these products are presented in table 2.–5.

For some purposes, particularly in machine computations, simple empirical formulas are desirable. An empirical formula for the K-shell photoeffect above 0.2 MeV is

$$\tau_K \cong Z^5 \sum_{n=1}^{4} \frac{a_n+b_nZ}{1+c_nZ} E^{-p_n} \left[\frac{\text{b}}{\text{atom}}\right], \qquad (2.–1)$$

TABLE 2.–4. *Total atomic photoeffect cross section τ_{pe} (b/atom), indicating the range of magnitudes*

Photon energy [MeV]	τ_{pe}			
	$_6$C	$_{26}$Fe	$_{82}$Pb	
0.01	$3.93\cdot10^1$	$1.59\cdot10^4$	$4.40\cdot10^4$	K-, L-edges
0.10	$2.16\cdot10^{-2}$	$1.89\cdot10^1$	$1.76\cdot10^3$	
1.0	$2.89\cdot10^{-5}$	$3.38\cdot10^{-2}$	$6.39\cdot10^0$	
10	$1.12\cdot10^{-6}$	$1.19\cdot10^{-3}$	$1.78\cdot10^{-1}$	
100	$1.01\cdot10^{-7}$	$1.04\cdot10^{-4}$	$1.41\cdot10^{-2}$	

for which the parameters a_n, b_n, c_n and p_n are given in table 2.–6. This formula goes to the Pratt [1960a] numerical values in the high energy limit and reproduces the combined experimental and theoretical data fairly well. Deviations from these data over most of the range 0.2 MeV $\lesssim E < \infty$ and $13 \lesssim Z \leqq 92$ are less than 1 to 2 percent, and in no case do they exceed 5 percent over this range. For other empirical formulas see Biggs and Lighthill [1967].

Total τ_{pe} values, such as those given in tables 2.–4 and –5, can be obtained approximately by multiplying τ_K by the ratios τ_{pe}/τ_K from table 2.–7. Hultberg [1959] suggested that, for practical purposes, this ratio is energy-independent, and the values in table 2.–7 are those derived by Davisson [1965] from the compilation by Kirchner [1930] of experimental K-edge data.

For elements $_1$H through $_{53}$I the Davisson-Kirchner ratios agree within 2 percent with the latest K-edge ratios in the compilation in progress by

TABLE 2.–5. *Scaled values of the total photoelectric cross section* τ_{pe}

Photon energy [MeV]	$_1$H [a]	$_6$C	$_{13}$Al	$_{20}$Ca	$_{26}$Fe	$_{29}$Cu
	τ_{pe} [b/atom] · $(E[\text{MeV}])^3 \cdot Z^{-4.5} \cdot 10^9$					
0.01	9.13	12.4	11.1	8.87	6.82	6.17
0.02	6.71	10.1	10.6	9.25	7.93	7.27
0.03	5.59	8.50	10.1	9.13	8.29	7.83
0.05	4.45	7.60	9.29	8.79	8.37	8.11
0.10	3.32	6.80	8.21	8.23	8.11	8.09
0.20	2.62	5.77	7.40	7.91	8.00	7.98
0.30	2.44	5.49	7.24	7.92	8.09	8.15
0.5	2.56	5.88	7.80	8.70	9.07	9.22
	τ_{pe}[b/atom] · $E[\text{MeV}] \cdot Z^{-4.5} \cdot 10^9$					
0.5	10.2	23.5	31.2	34.8	36.3	36.9
1.0	3.98	9.10	12.3	13.8	14.6	14.8
2	2.36	5.42	7.26	8.11	8.42	8.56
3	1.99	4.55	6.03	6.67	6.89	7.00
5	1.75	3.97	5.22	5.70	5.86	5.91
10	1.58	3.53	4.64	5.02	5.11	5.12
100	1.43	3.19	4.11	4.41	4.45	4.46
∞	1.41	3.15	4.04	4.33	4.37	4.39

Photon energy [MeV]	$_{42}$Mo	$_{50}$Sn	$_{74}$W	$_{82}$Pb	$_{92}$U	Absorption edges
	τ_{pe} [b/atom] · $(E[\text{MeV}])^3 \cdot Z^{-4.5} \cdot 10^9$					
0.01	0.663	0.619	0.108	0.108	0.0995	L_{III}
0.02	0.730	0.714	0.615	0.560	0.314	$L_{\text{II, I}}$
0.03	6.00	4.88	0.693	0.640	0.612	
0.05	6.74	5.70	0.779	0.744	0.740	
0.10	7.29	6.57	4.93	4.29	0.919	K
0.20	7.66	7.28	6.06	5.70	5.21	
0.30	8.06	7.83	6.91	6.79	6.25	
0.5	9.50	9.91	8.77	8.92	8.44	
	τ_{pe} [b/atom] · $E[\text{MeV}] \cdot Z^{-4.5} \cdot 10^9$					
0.5	38.0	39.6	35.1	35.7	33.8	
1.0	15.5	15.6	15.0	15.6	15.1	
2	8.77	8.73	8.25	8.64	8.26	
3	7.10	7.11	6.49	6.70	6.51	
5	5.92	5.86	5.19	5.30	5.11	
10	5.04	4.93	4.28	4.35	4.19	
100	4.30	4.16	3.56	3.44	3.49	
∞	4.22	4.11	3.50	3.39	3.44	

[a] $_1$H has only one K-shell electron, hence values in this column contain an additional factor of two to allow smooth interpolation to adjacent elements.

TABLE 2.–6. *Parameters for empirical fit [eq (2.–1)] to the K-shell photoelectric cross section* τ_K.

n	a_n	b_n	c_n	p_n
1	$1.6268 \cdot 10^{-9}$	$-2.683 \cdot 10^{-12}$	$4.173 \cdot 10^{-2}$	1
2	$1.5274 \cdot 10^{-9}$	$-5.110 \cdot 10^{-13}$	$1.027 \cdot 10^{-2}$	2
3	$1.1330 \cdot 10^{-9}$	$-2.177 \cdot 10^{-12}$	$2.013 \cdot 10^{-2}$	3.5
4	$-9.12 \cdot 10^{-11}$	0	0	4

TABLE 2.–7. *The experimental ratio* $(\tau_{pe}/\tau_K)_{K\text{-edge}}$ *as derived from Kirchner [1930] by Davisson [1965].*

Element	$(\tau_{pe}/\tau_K)_{K\text{-edge}}$	Element	$(\tau_{pe}/\tau_K)_{K\text{-edge}}$
$_1$H	1.00	$_{20}$Ca	1.11
$_4$Be	1.03	$_{26}$Fe	1.12
$_6$C	1.04	$_{29}$Cu	1.13
$_7$N	1.05	$_{42}$Mo	1.16
$_8$O	1.06	$_{50}$Sn	1.18
$_{11}$Na	1.075	$_{53}$I	1.19
$_{12}$Mg	1.08	$_{74}$W	1.20
$_{13}$Al	1.09	$_{79}$Pt	1.22
$_{14}$Si	1.09	$_{82}$Pb	1.22
$_{18}$Ar	1.10	$_{92}$U	1.235
$_{19}$P	1.10		

McMaster, Del Grande, et al. For the heavier elements $_{74}$W, $_{82}$Pb, and $_{92}$U some energy-dependence in the ratio τ_{pe}/τ_K is included, based on the Rakavy-Ron results, from the K-edge to about 1 MeV where the ratio joins smoothly with the values from table 2.–7.

Although not truly a smooth function of Z because of irregularities in the higher electron shell structure, the ratios in table 2.–7 can be represented with an accuracy of ± 2 to 3 percent by the empirical fit

$$\tau_{pe}/\tau_K \approx 1 + 0.01481 \ln^2 Z - 0.000788 \ln^3 Z. \qquad (2.\text{–}2)$$

2.4. Scattering

2.4.1. Compton Scattering. Klein-Nishina Formula

In Compton scattering, a photon collides with an electron, loses some of its energy and is deflected from its original direction of travel. The basic theory of this effect, assuming the electron to be initially free and at rest, is that of Klein and Nishina [1929]. This theory has been well confirmed experimentally (see, for example, Meitner and Hupfeld [1930], Hofstadter and McIntyre [1949], Cross and Ramsey [1950], French [1965], Sahota et al. [1966], and Gittelman et al. [1968]). Predictions of this theory have been summarized and extensive tabulations have been given by Nelms [1953], Burton [1953], and Evans [1958, 1968].

Over most of the region in which Compton scattering is a major part of the total cross section, the Klein-Nishina theory is directly applicable. Departures from it occur at low energies because of electron binding effects, and at high energies because of the possibility of emission of an additional photon (double Compton effect) and radiative corrections associated with emission and reabsorption of virtual photons. These corrections are discussed later in this section.

The relation between photon deflection and energy loss for Compton scattering, assuming the electron to be initially free and stationary, is determined from conservation of momentum and energy between the photon and the recoiling electron (Compton [1923], Debye [1923]). This relation can be expressed as

$$\frac{E'}{E} = \frac{1}{1 + (E/mc^2)(1 - \cos\theta)}, \qquad (2.\text{–}3)$$

where E and E' are the energies of the photon before and after the scattering, mc^2 is the electron rest energy and θ is the photon deflection angle.

In transport calculations it is often convenient to use, instead of the energy variable, the wavelength of the photon in Compton units,

$$\lambda = mc^2/E = 0.5110/E[\text{MeV}]. \qquad (2.\text{–}4)$$

The increase in wavelength associated with a Compton scattering event in these units is

$$\lambda' - \lambda = 1 - \cos\theta, \qquad (2.\text{–}5)$$

where λ and λ' are the Compton wavelengths of the photon before and after the deflection. The maximum shift in wavelength, occurring for a deflection $\theta = 180°$, is two Compton units.

For unpolarized photons the Klein-Nishina angular distribution function per steradian of solid angle Ω is

$$d\sigma_C^{KN}(\theta)/d\Omega = \tfrac{1}{2} r_e^2 [1 + k(1 - \cos\theta)]^{-2} \times$$
$$\times \left[1 + \cos^2\theta + \frac{k^2(1-\cos\theta)^2}{1 + k(1 - \cos\theta)}\right] \left[\frac{\text{cm}^2/\text{electron}}{\text{steradian}}\right], \qquad (2.\text{–}6)$$

in which k is the reciprocal of the incident photon Compton wavelength

$$k = 1/\lambda = E/mc^2 = E[\text{MeV}]/0.5110. \qquad (2.\text{–}7)$$

Integration of eq. (2.–6) over all angles gives the total Klein-Nishina cross section

$$\sigma_C^{KN}=2\pi r_e^2\left\{\frac{1+k}{k^2}\left[\frac{2(1+k)}{1+2k}-\frac{\ln(1+2k)}{k}\right]+\frac{\ln(1+2k)}{2k}-\frac{1+3k}{(1+2k)^2}\right\}\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right]. \quad (2.\text{–}8)$$

This formula is not particularly suitable for evaluation of σ_C^{KN} at low energies because of near-cancellation between the logarithmic and purely algebraic terms. For example, using 8-place arithmetic, errors of 1 to 2 percent will occur at 10 to 15 keV. Values of σ_C^{KN} in table 2.–8 were computed in double-precision arithmetic and we believe them correct to the 5 significant figures given.

For $k \ll 1$, eq. (2.–8) can be expanded as

$$\sigma_C^{KN}=\frac{8}{3}\pi r_e^2\frac{1}{(1+2k)^2}\left(1+2k+\frac{6}{5}k^2-\frac{1}{2}k^3+\frac{2}{7}k^4-\frac{6}{35}k^5+\frac{8}{105}k^6+\frac{4}{105}k^7-\cdots\right)\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right]. \quad (2.\text{–}9)$$

Using only terms through k^2, the value of σ_C^{KN} from eq. (2.–9) at 10 keV is within 0.001 percent of that from eq. (2.–8). In the low-energy limit ($k \to 0$) this expression becomes the classical Thomson cross section.[16]

$$\sigma_T=\frac{8}{3}\pi r_e^2=0.6652\cdot 10^{-24}\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right]. \quad (2.\text{–}10)$$

For $k \gg 1$, a useful approximation is (Heitler [1954]):

$$\sigma_C^{KN}\approx\pi r_e^2\frac{1+2\ln(2k)}{2k}\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right] \quad (2.\text{–}11)$$

which is equivalent to eq (2.–8) as $k\to\infty$, and gives a result differing by +0.6 percent at 100 MeV and by +0.09 percent at 1000 MeV.

In addition, Hastings [1955] has fitted eq (2.–8) by the empirical formula

$$\sigma_C^{KN}\approx\sigma_C^H=\pi r_e^2\left(\frac{c_1\xi+c_2\xi^2+c_3\xi^3}{1+d_1\xi+d_2\xi^2+d_3\xi^3}\right)\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right]. \quad (2.\text{–}12)$$

where $\xi=1/(1+bk)$. The parameters have the values

$b=0.222037$

$c_1=\ \ 1.651035$	$d_1=\ \ 12.501332$
$c_2=\ \ 9.340220$	$d_2=-14.200407$
$c_3=-8.325004$	$d_3=\ \ 1.699075$

For photon energies $0 \leqq E \leqq 1$ MeV values of σ_C^H are within 0.1 percent of σ_C^{KN}, and for $E \leqq 100$ MeV are within 1.3 percent. However, at 1 GeV values of σ_C^H are less than σ_C^{KN} by 17 percent, and at 100 GeV less by 44 percent.

Also listed in table 2.–8 are values of the Compton energy transfer fraction f_C^{KN} (for use in computing μ_K/ρ and μ_a/ρ but not μ_{en}/ρ) where

$$f_C^{KN}={}_a\sigma_C^{KN}/\sigma_C^{KN}. \quad (2.\text{–}13)$$

The numerator ${}_a\sigma_C^{KN}$ is obtained by weighting the right-hand side of eq (2.–6) by the fraction of the photon energy transferred to the recoil electron. This fraction is

$$\frac{k-k'}{k}=\frac{k(1-\cos\theta)}{1+k(1-\cos\theta)} \quad (2.\text{–}14)$$

where k' is the energy of the deflected photon. Combining eq (2.–6) with eq (2.–12) we have

$$d_a\sigma_C^{KN}(\theta)/d\Omega=\frac{1}{2}r_e^2\frac{k(1-\cos\theta)}{[1+k(1-\cos\theta)]^3}\times\left[1+\cos^2\theta+\frac{k^2(1-\cos\theta)^2}{1+k(1-\cos\theta)}\right]\left[\frac{\mathrm{cm}^2/\mathrm{electron}}{\mathrm{steradian}}\right]. \quad (2.\text{–}15)$$

Integration of the right-hand side of eq (2.–15) over all angles yields:

$${}_a\sigma_C^{KN}=2\pi r_e^2\left\{\frac{2(1+k)^2}{k^2(1+2k)}-\frac{1+3k}{(1+2k)^2}-\frac{(1+k)(2k^2-2k-1)}{k^2(1+2k)^2}-\frac{4k^2}{3(1+2k)^3}-\left(\frac{1+k}{k^3}-\frac{1}{2k}+\frac{1}{2k^3}\right)\ln(1+2k)\right\}\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right] \quad (2.\text{–}16)$$

At low photon energies eq (2.–16) suffers from loss of precision similar to that in eq. (2.–8). An expansion of eq (2.–16) useful for $k \ll 1$ is

$${}_a\sigma_C^{KN}=\frac{8}{3}\pi r_e^2\frac{1}{(1+2k)^3}\left(k+\frac{9}{5}k^2+\frac{3}{2}k^3-\frac{13}{35}k^4+\frac{2}{35}k^5+\frac{4}{35}k^6-\frac{4}{15}k^7+\cdots\right)\left[\frac{\mathrm{cm}^2}{\mathrm{electron}}\right]. \quad (2.\text{–}17)$$

2.4.2. Electron Binding Corrections to Compton Scattering. Rayleigh Scattering

In gamma ray transport theory and shielding calculations, electron binding effects have usually been either disregarded or treated very approximately by combining them with Rayleigh scattering. The justification for this treatment is that for low-Z

[16] However, extrapolation to this limit $[\sigma_C^{KN}]_{k\to 0}=\sigma_T$ is valid only for a free electron; for bound electrons $[\sigma_C]_{k\to 0}=0$.

TABLE 2.–8. *Compton scattering cross section σ_C for a free electron.*

These values were evaluated using eq. (2.–8) and modified by the Mork [1968] combined radiative and double-Compton corrections $\Delta\sigma^M$ here listed.

The average fraction of photon energy transferred to the electron, f_C, is also listed.

Photon energy	σ_C^{KN}	$\Delta\sigma_C^M$	$\sigma_C=\sigma_C^{KN}+\Delta\sigma_C^M$	f_C^{KN}	Photon energy	σ_C^{KN}	$\Delta\sigma_C^M$	$\sigma_C=\sigma_C^{KN}+\Delta\sigma_C^M$	f_C^{KN}
MeV	*b/electron*	*b/electron*	*b/electron*		*MeV*	*b/electron*	*b/electron*	*b/electron*	
0.010	0.64039	(0.00000)	(0.6404)	0.01876	40	0.017462	0.00012	0.01758	0.76004
.015	.62888	(.00001)	(.6289)	.02758	50	.014565	.00011	.01468	.76922
.02	.61791	(.00001)	(.6179)	.03605	60	.012541	.00010	.01264	.77624
.03	.59742	(.00002)	(.5974)	.05204	80	.0098806	.000090	.009970	.78650
.04	.57867	(.00002)	(.5787)	.06688	100	.0081976	.000082	.008280	.79385
.05	.56144	(.00003)	(.5615)	.08071	150	.0058182	.000075	.005893	.80600
.06	.54555	(.00003)	(.5456)	.09363	200	.0045506	.000070	.004620	.81379
.08	.51722	(.00004)	(.5173)	.11713	300	.0032086	.000067	.003276	.82378
.10	.49269	(.00005)	(.4927)	.13800	400	.0024992	.000066	.002565	.83024
.15	.44355	(.00007)	(.4436)	.18156	500	.0020568	.000067	.002124	.83493
.2	.40643	(.00008)	(.4065)	.21635	600	.0017531	.000065	.001818	.83858
.3	.35340	(.00010)	(.3535)	.26965	800	.0013609	.000059	.001420	.84402
.4	.31664	(.00013)	(.3168)	.30962	1000	.0011174	.000051	.001168	.84799
.5	.28913	(.00014)	(.2893)	.34136	1500	.00077951	(.0000362)	(.0008158)	.85471
.6	.26747	(.00016)	(.2676)	.36751	2000	.00060303	(.0000283)	(.0006314)	.85913
.8	.23493	(.00018)	(.2351)	.40866	3000	.00041929	(.0000197)	(.0004390)	.86492
1.0	.21118	(.00020)	(.2114)	.44004	4000	.00032365	(.0000152)	(.0003389)	.86874
1.5	.17156	(.00023)	(.1718)	.49468	5000	.00026462	(.0000124)	(.0002771)	.87156
2.0	.14634	(.00024)	(.1466)	.53084	6000	.00022439	(.0000105)	(.0002349)	.87378
3.0	.11508	(.00024)	(.1153)	.57732	8000	.00017288	(.0000081)	(.0001810)	.87713
4	.095963	.00024	.09620	.60693	10 000	.00014115	(.0000066)	(.0001478)	.87960
5	.082856	.00022	.08308	.62799	15 000	.000097550	(.00000458)	(.0001021)	.88386
6	.073221	.00020	.07342	.64400	20 000	.000074997	(.00000352)	(.00007852)	.88670
8	.059877	.00018	.06006	.66720	30 000	.000051721	(.00000243)	(.00005415)	.89047
10	.050983	.00017	.05115	.68356	40 000	.000039708	(.00000187)	(.00004157)	.89300
15	.037708	.00015	.03786	.71004	50 000	.000032335	(.00000152)	(.00003385)	.89488
20	.030246	.00014	.03039	.72656	60 000	.000027333	(.00000128)	(.00002862)	.89637
30	.021995	.00013	.02212	.74713	80 000	.000020958	(.00000099)	(.00002194)	.89864
					100 000	.000017051	(.00000080)	(.00001785)	.90033

elements the K-shell binding energies are low in comparison with the photon energies considered, while for high-Z materials with substantial K-shell binding energies these electrons are a small fraction of the total.

The scattering of 0.662-MeV photons by K-shell electrons of various heavy atoms has been measured by Motz and Missoni [1961], Sujkowski and Nagel [1961], and Varma and Eswaran [1962]. The ratio of the observed differential cross section $d\sigma_C^K(\theta)/d\Omega$ to the Klein-Nishina differential cross section $d\sigma_C^{KN}(\theta)/d\Omega$ [eq (2.–6)] for tin and gold is given in figure 2.–2, based on data of Motz and Missoni. It is seen that for small angles the effect of binding is to *decrease* the cross section, whereas for large angles an *increase* occurs. The decrease and increase tend to compensate each other, so that for the cases shown in figure 2.–2 the integrated cross sections σ_C and σ_C^{KN} [eq (2.–8)] agree within experimental error. Similar measurements by Dowe [1965] on thallium K-shell electrons suggest such compensation may extend down to 0.122 MeV.

The usual Klein-Nishina cross section, which assumes that the target electron is free and at rest, has been generalized by Jauch and Rohrlich [1955] to the case where the electron is free but in motion. Motz and Missoni used this generalized theory to interpret their data at large angles. Their results, obtained by averaging over the appropriate electron velocity distributions, are shown as the solid curves in figure 2.–2.

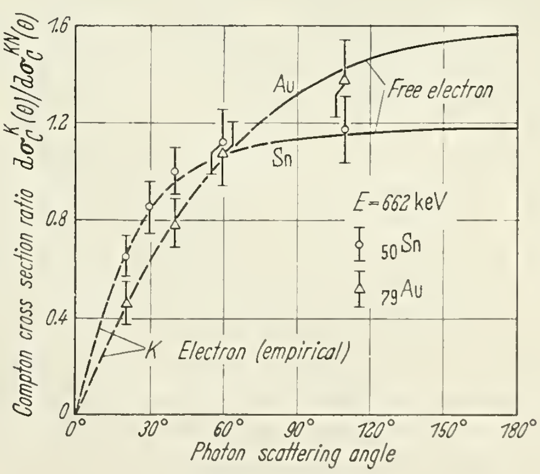

FIGURE 2.–2. *Ratio of observed Compton scattering from* K*-shell electrons (Motz and Missoni [1961]) to Klein-Nishina theory, eq. (2.–6).*

The solid curves are extrapolations (by Motz and Missoni) to $\theta = 180°$ using theory of Jauch and Rohrlich [1955] which considers electron velocities.

The binding corrections have usually been treated in the impulse approximation, taking into account not only the K-shell, but all the atomic electrons. This involves applying a multiplicative correction, the so-called "incoherent scattering function," $S(q, Z)$, to the differential Klein-Nishina formula [eq. (2.–6)]

$$d\sigma_C(\theta)/d\Omega = S(q, Z)\, d\sigma_C^{KN}(\theta)/d\Omega. \qquad (2.\!-\!18)$$

The momentum transfer q is related to the photon energies and deflection angle θ according to

$$q = \sqrt{k^2 + k'^2 - 2kk' \cos\theta}, \qquad (2.\!-\!19)$$

or, using eq (2.–3),

$$q = 2k \sin\frac{\theta}{2} \cdot \sqrt{1 + (k^2 + 2k)\sin^2\theta / (1 + 2k \sin^2\theta)}, \qquad (2.\!-\!20)$$

where q is in mc units and k and k' are the photon energies (in mc^2 units) before and after the deflection. Since binding effects are important mainly for small momentum transfers, the approximation $k - k' \approx 0$ is usually made, so that

$$q \approx 2k \sin\frac{\theta}{2}. \qquad (2.\!-\!21)$$

The incoherent scattering function $S(q, Z)$ represents the probability that an atom be raised to any excited or ionized state as a result of a sudden impulsive action which imparts a recoil momentum q to an atomic electron. For K-shell electrons only, $S(q, Z)$ would correspond to the ratios shown in figure 2.–2.

Rayleigh scattering is a process by which photons are scattered by bound atomic electrons and in which the atom is neither ionized nor excited. The scattering from different parts of the atomic charge distribution is then "coherent," i.e., there are interference effects.

This process occurs mostly at low energies and for high Z materials, in the same region where electron binding effects influence the Compton scattering cross section. Indeed, if each atomic electron contributed independently to the cross section, the onset of Rayleigh scattering for low momentum transfer would exactly compensate for the reduction of Compton scattering due to binding. However, the various atomic electrons contribute coherently to Rayleigh scattering, greatly increasing the probability for the process.

We shall restrict the following discussion to Rayleigh scattering in the narrower sense, in which the coherence extends only over the Z electrons of individual atoms. This coherence can also extend to electrons of different atoms to give more striking interference effects, such as Bragg-law diffraction by crystal lattices.

Experimental studies of Rayleigh scattering have been made by Moon [1950], Storruste [1950], Wilson [1951], Mann [1956], Schopper [1957], Storruste and Tjóm [1958], Anand, Singh, and Sood [1963, 1964], and Nath and Ghose [1964]. In interpreting these measured data, one must also take into account other, much less probable, elastic or quasi-elastic scattering processes, such as Thomson scattering by the nucleus, nuclear resonance scattering, and Delbrück scattering (see sec. 2.2.), in addition to Rayleigh scattering. Theoretical information on these processes, including constructive interference effects between the different processes, has been summarized by Moon [1950] and by Jauch and Rohrlich [1955].

Detailed Rayleigh scattering calculations have been made by Levinger [1952] for K-shell electrons of tin, and by Brown et al. [1954–1957] for K-shell electrons of mercury. In practice, it is necessary to consider the charge distribution of all Z electrons at once. This can be done approximately through use of an "atomic form factor" $F(q, Z)$ based on the Thomas-Fermi, Hartree, or other model of the atom. The square of this form factor, $[F(q, Z)]^2$, is the probability that the Z electrons of an atom take up a recoil momentum, q, without absorbing any energy. In this process q is well-represented by (eq (2.–21) since it is assumed that $k - k' = 0$. The above probability $[F(q, Z)]^2$, is combined with the low-energy limiting form of the Klein-Nishina differential formula [eq (2.–6)] to give the differential Rayleigh scattering cross section for unpolarized photons:

$$d\sigma_R(\theta)/d\Omega = \frac{r_e^2}{2}\,(1 + \cos^2\theta)\,[F(q, Z)]^2 \left[\frac{\text{cm}^2/\text{atom}}{\text{steradian}}\right]. \qquad (2.\!-\!22)$$

Calculations of $S(q, Z)$ and $F(q, Z)$ depend on knowledge of the atomic wave functions; they can be done analytically for hydrogen and, for other atoms, in various approximations based on the Thomas-Fermi, Hartree, or other models. The procedures used in such calculations have been discussed by White-Grodstein [1957] for $S(q, Z)$ and by Nelms and Oppenheimer [1955] for $F(q, Z)$.

Evaluations of σ_C^{BD} have until recently used $S(q, Z)$ values based on the Thomas-Fermi model.[17] However, Cromer and Mann [1967] have now provided Hartree-Fock $S(q, Z)$ data for the 39 spherically symmetric atoms. Corresponding Hartree-model tabulations of $F(q, Z)$ have been given by Hanson et al. [1964] and by Cromer and Waber [1965].

---

[17] In addition to the Grodstein [1957] (and Davisson [1965]) results, extensive evaluations of σ^{BD} based on the Thomas-Fermi model have been given by Brown [1966b] $1 \leqslant Z \leqslant 100$, 1 keV to MeV and by Veigele [1965]: $1 \leqslant Z \leqslant 106$, 0.1 keV to 1 MeV.

Storm and Israel [1967] have used $S(q, Z)$ values of Cromer and Mann (and additional data from Cromer) and $F(q, Z)$ values from Hanson et al. to calculate σ_C^{BD} and σ_R (integrating over equations (2.–18) and (2.–22), respectively) for all elements $Z=1$ to 100 and energies ranging up from 1 keV. Figure 2.–3 shows ratios of these values of σ_C^{BD} (excluding interpolated values) to values given by the Klein-Nishina formula [eq (2.–8)] for photon energies of 1, 10, and 100 keV.

Cumulative angular distributions of σ_R, based on values of $F(q, Z)$ from Nelms and Oppenheim [1955], are displayed in figure 2.–4 for C, Fe, and Hg. At high energies it is seen that Rayleigh scattering is confined to small angles (at 1 MeV more than half the photons are scattered by less than 5°). At low energies, particularly for high-Z materials, the angular distribution is much broader. Here, however, the Rayleigh scattering cross section is small in comparison with photoelectric absorption. On the basis of these considerations, Rayleigh scattering is frequently disregarded in gamma ray transport theory and shielding calculations (Fano, Spencer, and Berger [1959], Goldstein and Wilkins [1954]).

Rayleigh scattering can, however, be of importance in interpreting "narrow beam" attenuation coefficient measurements, depending on the angular resolution of the apparatus. A useful simple criterion for judging the angular spread of Rayleigh scattering is (Moon [1950], Evans [1958]):

$$\theta_c = 2 \arcsin \left[\frac{0.0133 Z^{1/3}}{E[\mathrm{MeV}]}\right], \qquad (2.\text{–}23)$$

where θ_c is the opening half-angle of a cone containing at least 75 percent of the Rayleigh-scattered photons (see also fig. 2.–4).

The sum $(\sigma_C^{BD}+\sigma_R)$, rather than σ_C^{BD} and σ_R individually, has been tabulated in previous compilations (White-Grodstein [1957] and Davisson [1965]), because this sum is less sensitive to errors from approximations in the theory. In this report, since present theory still relies on the impulse approximation and neglects initial motion of the electrons, we retain the White-Grodstein format in our tables in section 3. That is, in tables 3.–1 to 3.–36 we list the sum $(\sigma_C^{BD}+\sigma_R)$ (or "scattering, with coherent" in the notation of White-Grodstein and Davisson), in which σ_C^{BD} and σ_R are the values given by Storm and Israel [1967]. Also, in table 2.–9 we give these results in the form of a percentage correction to the total "without coherent" cross section, σ_{tot}, given in table 1.–4, viz

$$\frac{(\sigma_C^{BD}+\sigma_R)-\sigma_C^{KN}}{\sigma_{\mathrm{tot}}} \times 100\%. \qquad (2.\text{–}24)$$

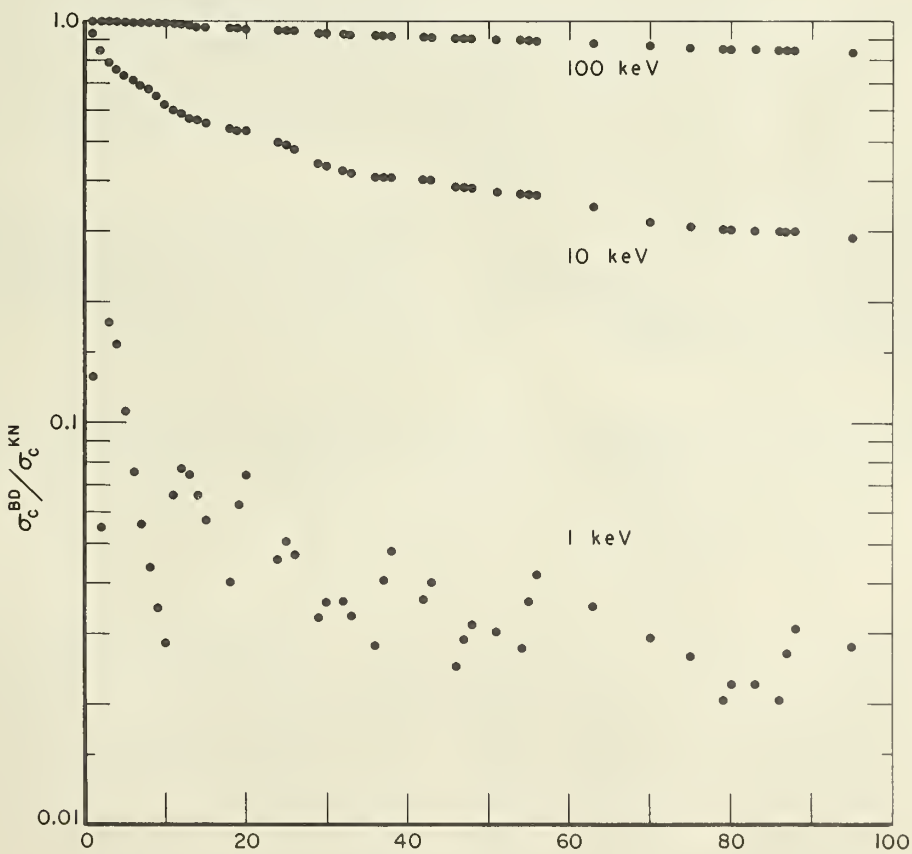

FIGURE 2.–3. *Ratio of the bound-electron Compton collision cross section, σ_C^{BD} calculated by Storm and Israel [1967] to that for free electrons, σ_C^{KN}, evaluated from the Klein-Nishina formula.*

At energies above 100 keV the sum $(\sigma_C^{BD} + \sigma_R)$ given by Storm and Israel (based entirely on the Hartree model) is within 1 percent of that given by White-Grodstein and Davisson (based mostly on the Thomas-Fermi model). However, between 10 and 100 keV there are differences of as much as 10 percent in either direction.

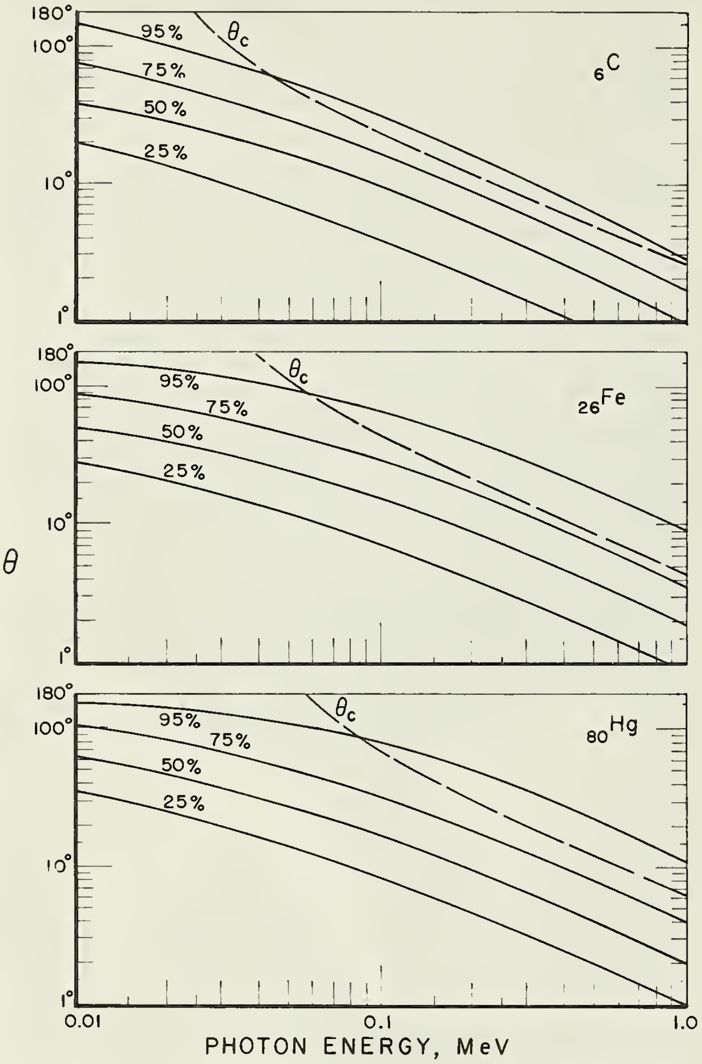

FIGURE 2.–4. *Opening half-angle, θ, of cone containing 25 percent, 50 percent, 75 percent, and 95 percent, respectively, of photons Rayleigh-scattered from* C, Fe, *and* Hg.

The function θ_c (Eq. 2.–23) is included for comparison.

2.4.3. Radiative Corrections. Double Compton Effect

The radiative correction (of the order 1/137) is associated with emission and reabsorption of virtual photons whereas in the double Compton effect an additional real photon, usually very low in energy, is emitted.

Because of the predominance of pair production at high energies, experimental data on these effects are difficult to obtain and the existing experiments by Cavanagh [1952], Bracci et al. [1956], Theus and Beach [1957], and Burdet [1963] have large uncertainties. Hence, the information is primarily theoretical and has only recently become sufficiently quantitative for inclusion in tabulations. We have relied on the recent theoretical results of Mork [1968] who made a calculation combining the radiative correction σ(rad. corr.) with the cross section σ(double Compt.) for the double Compton effect.

The differential formulas (Brown and Feynman [1952], Mandl and Skyrme [1952]) for the two effects each contain an "infrared divergence." These divergencies are of opposite sign, and in the combined calculation they cancel each other to give a physically meaningful result.

The Mork correction, which must be added to the Klein-Nishina cross section,

$$\Delta\sigma_C^M = \sigma(\text{double Compt.}) + \sigma(\text{rad. corr.}) \qquad (2.\text{–}25)$$

is given in table 2.–8 separately and in the combination with σ_C^{KN}. It is seen that the contribution of $\Delta\sigma_C^M$ to σ_C is ~ 0.25 percent at 4 MeV, rising to ~ 1 percent at 100 MeV and ~ 5 percent at 1000 MeV.

TABLE 2.–9. *Percentage by which σ_{tot} or μ/ρ is increased if coherent scattering effects are included.*

Based on data by Storm and Israel [1967] taking into account Rayleigh scattering and the effect of electron binding on Compton scattering

Photon energy [MeV]	$_1$H	$_6$C	$_{13}$Al	$_{20}$Ca	$_{26}$Fe	$_{29}$Cu	$_{42}$Mo	$_{50}$Sn	$_{74}$W	$_{82}$Pb	$_{92}$U	Absorption edges
0.01	−.2	5.2	1.9	0.9	0.7	0.6	2.6	1.8	4.8	3.8	3.1	L_{III}-edge
0.02	−.1	10.7	5.3	2.7	1.9	1.7	8.0	5.8	3.0	2.7	3.7	$L_{II,I}$-edges
0.03	0	9.0	8.4	4.6	3.2	2.8	1.8	1.6	5.2	4.5	3.7	
0.05	0	4.7	10.6	7.9	5.7	5.1	3.2	2.8	9.4	8.1	6.6	
0.10	0	1.4	5.8	8.4	8.2	8.0	5.9	5.0	3.4	3.3	11.7	K-edge
0.20	0	0.5	2.0	3.8	5.0	6.0	7.2	6.9	5.3	4.9	4.4	
0.30	0	< 0.5	1.0	2.0	3.1	3.6	5.8	6.2	5.8	5.4	5.0	
0.50	0	< 0.5	< 0.5	0.9	1.3	1.7	2.8	3.8	5.0	4.8	4.7	
1.0	0	< 0.5	< 0.5	< 0.5	< 0.5	0.5	1.1	1.2	2.2	2.6	2.8	
2.0	0	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.8	1.1	0.9	
3.0	0	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.6	

2.5. Electron-Positron Pair Production

2.5.1. General Discussion

In this effect, which is the most likely photon interaction at high energies, a photon disappears in the field of a charged particle, and an electron-positron pair appears. The cross section κ_n for pair production in the field of a nucleus varies as

$$\kappa_n \sim Z^2. \qquad (2.–26)$$

The cross section κ_e in the field of all the atomic electrons varies as Z times the square of the unit charge, or,

$$\kappa_e \sim Z, \qquad (2.–27)$$

and is of minor importance except for the lowest-Z materials. The ratio κ_e/κ_n can be set equal to η/Z where η is a slowly varying function of Z and E, generally close to one, and will be discussed later in this section.

There have been a number of experimental studies in which the κ_n and κ_e cross sections have been isolated to some extent. For κ_n data see, for example, the results by Standil and Shkolnik [1958], Singh et al. [1959], Rao et al. [1968], Plimpton and Hammer [1963], Yamazaki and Hollander [1965], and Titus and Levy [1966], and for κ_e data, the results of Criegee [1960], Sandhu et al. [1962], and Frei et al. [1964]. Earlier results for both cross sections have been summarized by Davisson [1965]. There are additional data which depend on subtraction of the Compton cross section σ_C^* from measured total cross sections σ_{tot} (see, for example, Jones [1959, 1960], Wyckoff and Koch [1960]), but the recent Mork correction $\Delta\sigma_C^M$ to σ_C^{KN} requires slight revisions in these estimates. These data still leave wide gaps or contain substantial uncertainties. For tabulations we rely heavily on theory, as discussed in the remainder of this section.

2.5.2. Pair Production in the Field of the Nucleus

The threshold for this effect is equal to the combined rest energies of the created pair $2mc^2$ ($=1.022$ MeV). The cross section rises monotonically from zero at threshold, varying approximately linearly with E, until it levels off near 50 MeV for high-Z materials and at higher energies for low-Z materials. At 100, 1000 and 10,000 MeV the cross section is roughly 75 percent, 95 percent, and 99 percent, respectively, of its high-energy limiting value.

The values of κ_n we present in table 2.–10 and in section 3 have been revised to incorporate new screening calculations by Sörenssen [1965, 1966] and the Mork-Olsen [1965] radiative correction. However, it is useful to describe first the procedures and sources of information for the well-established

TABLE 2.–10. *Scaled cross section κ_n/Z^2 for pair production in the field of the nucleus, based on κ_n^{BH} (Born) evaluated by Maximon [1968], screening (Hartree-Fock-Slater) estimates by Sörenssen [1965, 1966], the Mork-Olsen [1965] radiative correction, and corrections to the Born approximation by empirical adjustment of the Coulomb correction.*

Units are [b/atom]/Z^2. For unscaled κ_n values up to 100 GeV, see tables in section 3.

Photon energy [MeV]	$_1$H	$_6$C	$_{13}$Al	$_{20}$Ca	$_{26}$Fe	$_{29}$Cu
1.022	0	0	0	0	0	0
1.5	$4.35\cdot10^{-5}$	$4.37\cdot10^{-5}$	$4.45\cdot10^{-5}$	$4.62\cdot10^{-5}$	$4.81\cdot10^{-5}$	$4.92\cdot10^{-5}$
2	$1.79\cdot10^{-4}$	$1.79\cdot10^{-4}$	$1.81\cdot10^{-4}$	$1.84\cdot10^{-4}$	$1.88\cdot10^{-4}$	$1.90\cdot10^{-4}$
3	$5.12\cdot10^{-4}$	$5.11\cdot10^{-4}$	$5.13\cdot10^{-4}$	$5.16\cdot10^{-4}$	$5.19\cdot10^{-4}$	$5.21\cdot10^{-4}$
5	$1.11\cdot10^{-3}$	$1.11\cdot10^{-3}$	$1.11\cdot10^{-3}$	$1.11\cdot10^{-3}$	$1.10\cdot10^{-3}$	$1.10\cdot10^{-3}$
10	$2.15\cdot10^{-3}$	$2.14\cdot10^{-3}$	$2.12\cdot10^{-3}$	$2.10\cdot10^{-3}$	$2.09\cdot10^{-3}$	$2.08\cdot10^{-3}$
20	$3.30\cdot10^{-3}$	$3.28\cdot10^{-3}$	$3.23\cdot10^{-3}$	$3.20\cdot10^{-3}$	$3.17\cdot10^{-3}$	$3.15\cdot10^{-3}$
30	$3.99\cdot10^{-3}$	$3.95\cdot10^{-3}$	$3.88\cdot10^{-3}$	$3.84\cdot10^{-3}$	$3.79\cdot10^{-3}$	$3.78\cdot10^{-3}$
50	$4.87\cdot10^{-3}$	$4.76\cdot10^{-3}$	$4.67\cdot10^{-3}$	$4.60\cdot10^{-3}$	$4.54\cdot10^{-3}$	$4.52\cdot10^{-3}$
100	$6.05\cdot10^{-3}$	$5.76\cdot10^{-3}$	$5.61\cdot10^{-3}$	$5.50\cdot10^{-3}$	$5.42\cdot10^{-3}$	$5.39\cdot10^{-3}$
Photon energy [MeV]	$_{42}$Mo	$_{50}$Sn	$_{74}$W	$_{82}$Pb	$_{92}$U	
1.022	0	0	0	0	0	
1.5	$5.55\cdot10^{-5}$	$6.01\cdot10^{-5}$	$7.67\cdot10^{-5}$	$8.27\cdot10^{-5}$	$9.03\cdot10^{-5}$	
2	$2.02\cdot10^{-4}$	$2.10\cdot10^{-4}$	$2.42\cdot10^{-4}$	$2.53\cdot10^{-4}$	$2.68\cdot10^{-4}$	
3	$5.33\cdot10^{-4}$	$5.42\cdot10^{-4}$	$5.74\cdot10^{-4}$	$5.86\cdot10^{-4}$	$6.01\cdot10^{-4}$	
5	$1.10\cdot10^{-3}$	$1.10\cdot10^{-3}$	$1.09\cdot10^{-3}$	$1.08\cdot10^{-3}$	$1.08\cdot10^{-3}$	
10	$2.03\cdot10^{-3}$	$1.99\cdot10^{-3}$	$1.87\cdot10^{-3}$	$1.83\cdot10^{-3}$	$1.77\cdot10^{-3}$	
20	$3.06\cdot10^{-3}$	$3.00\cdot10^{-3}$	$2.79\cdot10^{-3}$	$2.72\cdot10^{-3}$	$2.62\cdot10^{-3}$	
30	$3.67\cdot10^{-3}$	$3.59\cdot19^{-3}$	$3.35\cdot10^{-3}$	$3.27\cdot10^{-3}$	$3.16\cdot10^{-3}$	
50	$4.38\cdot10^{-3}$	$4.29\cdot10^{-3}$	$4.00\cdot10^{-3}$	$3.90\cdot10^{-3}$	$3.78\cdot10^{-3}$	
100	$5.20\cdot10^{-3}$	$5.08\cdot10^{-3}$	$4.74\cdot10^{-3}$	$4.63\cdot10^{-3}$	$4.48\cdot10^{-3}$	

White-Grodstein [1957] compilation, and then note how the present evaluation differs.

White-Grodstein used as an initial approximation the Bethe-Heitler theory done in the Born approximation (Bethe and Heitler [1934], Heitler and Sauter [1933], and Racah [1934, 1935]). In the energy region $E < 5$ MeV, where screening effects are negligible, cross section values for an unscreened nucleus were obtained from a formula of Hough [1948], which fits the Bethe-Heitler results to 0.1 percent. For $E >> 5$ MeV the differential Bethe-Heitler formula, including screening based on the Thomas-Fermi model of the atom (Bethe and Heitler [1934, eq (36)], also Bethe and Ashkin [1953, eq (114)]), was integrated numerically over the energy distribution between the pair particles to obtain κ_n^{BH}(Born).

Corrections to the Born approximation values were applied at all energies. These corrections were derived from:

(1) Calculations of Jaeger and Hulme in the energy range $E < 5$ MeV,

(2) Calculations of Davies, Bethe and Maximon for $E \geqslant 5$ MeV, and

(3) Experimental data.

The results of Jaeger and Hulme [1936] and Jaeger [1936, 1941] were obtained by numerical solution of the Dirac equation and indicate considerable departures from the Born approximation near threshold, especially for high-Z elements. For example, for tin at 3 mc^2 (=1.533 MeV) the ratio of their result to that from formulas based on the Born approximation is 1.30, while for lead at $3mc^2$ this ratio is 1.97, dropping to 1.24 at $5.2mc^2$ (=2.66 MeV).[18]

The calculation of Davies, Bethe, and Maximon [1954] for an unscreened nucleus went beyond the Born approximation, using Sommerfeld-Maue [1935] wave functions rather than plane waves. Their results lead to the appearance of a negative Coulomb correction

$$-\Delta\kappa_n^{DBM} = -\frac{28}{9}\frac{Z^2 r_e^2}{137} f(Z), \qquad (2.–28)$$

where $f(Z)$ may be evaluated from the sum

$$f(Z) = a^2[(1+a^2)^{-1} + 0.20206 - 0.0369\, a^2 + 0.0083\, a^4 - 0.002\, a^6 + \cdot\cdot\cdot], \qquad (2.–29)$$

in which

$$a = Z/137.$$

In their approximation (neglect of terms of order $\ln k/k$ and $1/k$) the Coulomb correction remains the same whether screening is absent, partial, or complete.

In her tabulations in the energy range $E < 5$ MeV, White-Grodstein used the Hough formula to calculate κ_n^{BH}(Born) and then applied graphically-interpolated values of the Jaeger-Hulme correction. In the range $E > 5$ MeV she fitted the relevant corrections by a semi-empirical formula

$$\kappa_n(\text{White-Grodstein}) = \kappa_n^{BH}(\text{Born}) - \Delta\kappa_n^{DBM} + b^2\frac{\ln k}{k}, \qquad (2.–30)$$

where the terms κ_n^{BH}(Born) and $-\Delta\kappa_n^{DBM}$ were computed as explained above. The additional term $b^2(\ln k)/k$ was adjusted to give better agreement with experimental data, particularly those of Colgate [1952] and Paul [1954] and to provide a smooth transition to the low-energy results of Jaeger and Hulme.

In the present revision, use was made of a slightly different semiempirical formula

$$\kappa_n = [\kappa_n^{BH}\ (\text{Born, unscreened}) - s^{HFS}] \cdot [1 + \Delta\ (\text{rad. corr.})] - \Delta\ (\text{empirical}) \cdot \Delta\kappa_n^{DBM}, \qquad (2.–31)$$

which, although not necessarily more accurate than eq. (2.–30), covers the entire energy range from threshold to the high energy limit. Values of κ_n computed using eq (2.–31) are presented in table 2.–10 in the scaled form κ_n/Z^2 for ease of interpolation.

New data taken into account in this revision are:

(a) the near-threshold expressions by Maximon [1968] of κ_n^{BH} (Born, unscreened) as given in equations (2.–34) and (2.–36),

(b) the screening correction s^{HFS} (in table 2.–13) calculated by Sörenssen [1965, 1966] using Hartree-Fock-Slater wave functions (Hanson et al. [1964]) for $0 \leqslant q \leqslant 0.3$ and the Thomas-Fermi model of the atom for $0.3 \leqslant q \leqslant 8.0$ where q is momentum transfer in mc units,

(c) the radiative correction of Mork and Olsen [1965] given in table 2.–11, and

(d) an empirical correction to the Born approximation entered as an energy-dependent correction factor (given in table 2.–11) applied to the high-energy Coulomb correction $\Delta\kappa_n^{DBM}$ given in table 2.–12, since both corrections vary approximately as Z^4 and are large and of opposite sign near threshold.[19] The latter correction takes into account additional κ_n experimental data including measurements by Standil and Shkolnik [1958] and Titus and Levy [1966], and total attenuation data by Barkan [1956], Hübel, Röh, and Scheer [1959] and Barlett and Donahue [1965].

[18] Recently Øverbø [1967] has extended the Jaeger-Hulme results to include 8 elements $_6$C through $_{92}$U and energies ranging from 2.001 mc^2 (1.0225 MeV) to 6.5 mc^2 (3.32 MeV).

[19] Maximon has derived an energy dependence (see table 2.–11) for the Coulomb correction, giving the modified correction $[1-(2/7)(9k^{-1}-6k^{-2}+4k^{-3})]\cdot\Delta\kappa_n^{DBM}$, as quoted by Koch [1964] and Sörenssen [1965, 1966], which goes to zero at threshold. However, this improved Coulomb correction still results in a negative theoretical cross section near threshold if no empirical correction term is added.

TABLE 2.–11. *Energy-dependent parameters used for evaluating κ_n.*

Photon energy [MeV]	κ_n^{BH}(Born) [b/atom]/Z^2	Mork-Olsen radiative correction factor [$1+\Delta$(rad. corr.)]	Empirical multiplier for Coulomb correction	Theoretical multiplier for Coulomb correction
1.022	0	1.000	0	0
1.5	$4.30 \cdot 10^{-5}$	(1.011)	−0.0677	0.2778
2	$1.772 \cdot 10^{-4}$	(1.012)	−0.1286	0.4359
3	$5.055 \cdot 10^{-4}$	(1.012)	−0.1356	0.6061
4	$8.205 \cdot 10^{-4}$	(1.013)	−0.0639	0.6971
5	$1.100 \cdot 10^{-3}$	(1.013)	+0.0204	0.7539
6	$1.350 \cdot 10^{-3}$	(1.013)	0.1216	0.7927
8	$1.775 \cdot 10^{-3}$	(1.013)	0.305	0.8425
10	$2.127 \cdot 10^{-3}$	1.012	0.450	0.8729
15	$2.792 \cdot 10^{-3}$	1.012	0.655	0.9144
20	$3.278 \cdot 10^{-3}$	1.011	0.740	0.9354
30	$3.977 \cdot 10^{-3}$	1.011	0.824	0.9567
40	$4.479 \cdot 10^{-3}$	1.011	0.871	0.9674
50	$4.872 \cdot 10^{-3}$	1.011	0.900	0.9739
60	$5.194 \cdot 10^{-3}$	1.011	0.924	0.9782
80	$5.705 \cdot 10^{-3}$	1.010	0.954	0.9837
100	$6.102 \cdot 10^{-3}$	1.010	0.976	0.9869

TABLE 2.–12. *Davies-Bethe-Maximon [1954] high-energy Coulomb correction, $-\Delta\kappa_n^{DBM}$, divided by Z^2.*

Units are [b/atom]/Z^2.

Z	$-\Delta\kappa_n^{DBM}/Z^2$	Z	$-\Delta\kappa_n^{DBM}/Z^2$
1	$-1.15 \cdot 10^{-7}$	18	$-3.684 \cdot 10^{-5}$
4	$-1.84 \cdot 10^{-6}$	19	$-4.097 \cdot 10^{-5}$
5	$-2.88 \cdot 10^{-6}$	20	$-4.532 \cdot 10^{-5}$
6	$-4.15 \cdot 10^{-6}$	26	$-7.566 \cdot 10^{-5}$
7	$-5.64 \cdot 10^{-6}$	29	$-9.344 \cdot 10^{-5}$
8	$-7.36 \cdot 10^{-6}$	42	$-1.884 \cdot 10^{-4}$
11	$-1.388 \cdot 10^{-5}$	50	$-2.591 \cdot 10^{-4}$
12	$-1.651 \cdot 10^{-5}$	53	$-2.876 \cdot 10^{-4}$
13	$-1.935 \cdot 10^{-5}$	74	$-5.078 \cdot 10^{-4}$
14	$-2.241 \cdot 10^{-5}$	82	$-5.977 \cdot 10^{-4}$
15	$-2.569 \cdot 10^{-5}$	92	$-7.119 \cdot 10^{-4}$
16	$-2.919 \cdot 10^{-5}$		

The differential Bethe-Heitler Born-approximation cross section, in the high-energy approximation and for partial screening, can be approximated by use of a simple and convenient formula derived by Bernstein [1950]. In this approximation the Bethe-Heitler screening functions φ_1 and φ_2 (based on the Thomas-Fermi atom) are assumed to be equal, and φ_1 is fitted by an analytic expression to better than 2 percent. In terms of the photon energy k and the outgoing electron kinetic energy T, both in mc^2 units, the resulting formula is

$$d\kappa_n^{BH}\,(\mathrm{Born})/dT$$

$$\approx \frac{4Z^2r_e^2}{137} \ln(183\,Z^{-1/3}) \frac{1}{k}\left[1-u\,\frac{T+1}{k}+u\left(\frac{T+1}{k}\right)^2\right]$$

$$\times\left[1-\frac{Kk}{(T+1)(k-T-1)}\right]^{-1}, \qquad (2.\text{–}32)$$

where

$$u=\frac{4}{3}+[9\ln(183\,Z^{-1/3})]^{-1}$$

and

$$K=255\,Z^{-1/3}/(15.6-\tfrac{4}{3}\ln Z).$$

This formula can be integrated analytically to give the total pair production cross section:

$$\kappa_n^{BH}(\mathrm{Born})\approx\frac{4Z^2r_e^2}{137}\ln(183\,Z^{-1/3}\left[\left(1-\frac{2}{k}\right)\right.$$

$$\times\left(1+\frac{uK}{k}\right)-\frac{u}{6}-\frac{2}{k}+\frac{u}{k^2}-\frac{2u}{3k^3}-\frac{2K}{k}$$

$$\left.\times\frac{\left(1+\frac{uK}{k}\right)}{\sqrt{1+\frac{4K}{k}}}\ln\frac{\sqrt{1+\frac{4K}{k}}+1-\frac{2}{k}}{\sqrt{1+\frac{4K}{k}}-1+\frac{2}{k}}\right]. \qquad (2.\text{–}33)$$

If the Bernstein formula (2.–33) is inserted into eq (2.–31) we obtain values of κ_n which agree with those in table 2.–10 and with experimental data to ~ 5 percent over the energy range $E \gtrsim 5$ MeV for $Z \gtrsim 29$. For lighter materials this agreement is restricted to higher energies: e.g., for carbon the Bernstein result is lower by ~ 20 percent over the range 5 to 20 MeV but agrees within ~ 5 percent for $E > 50$ MeV. However, for these materials the addition of the contribution of Compton scattering results in total photon inter-

TABLE 2.–13. *Sörenssen [1965, 1966] screening (Hartree-Fock-Slater) corrections, s^{HFS}, to be subtracted from κ_n^{BH} (Born) divided by Z^2.*

Since s^{HFS} is not a smoothly varying function of Z near $_1$H, values of s^{HFS}/Z^2 for 2, 3, and 4 are included. Values below 10 MeV are extrapolated. Units are [b/atom]/Z^2.

Photon energy [MeV]	$_1$H	$_2$He	$_3$Li	$_4$Be	$_6$C	$_{13}$Al	$_{20}$Ca
1.022	0	0	0	0	0	0	0
1.5	—	—	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-7}$	$3.0 \cdot 10^{-7}$	$4.0 \cdot 10^{-7}$
2	—	$3.0 \cdot 10^{-7}$	$3.0 \cdot 10^{-7}$	$3.0 \cdot 10^{-7}$	$4.0 \cdot 10^{-7}$	$6.0 \cdot 10^{-7}$	$8.0 \cdot 10^{-7}$
3	$2.0 \cdot 10^{-7}$	$8.0 \cdot 10^{-7}$	$9.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$	$2.3 \cdot 10^{-6}$
5	$8.0 \cdot 10^{-7}$	$2.1 \cdot 10^{-6}$	$2.3 \cdot 10^{-6}$	$2.6 \cdot 10^{-6}$	$3.3 \cdot 10^{-6}$	$5.0 \cdot 10^{-6}$	$6.6 \cdot 10^{-6}$
10	$4.0 \cdot 10^{-5}$	$6.2 \cdot 10^{-6}$	$6.7 \cdot 10^{-6}$	$7.5 \cdot 10^{-6}$	$9.4 \cdot 10^{-6}$	$2.01 \cdot 10^{-5}$	$2.71 \cdot 10^{-5}$
20	$1.51 \cdot 10^{-5}$	$1.65 \cdot 10^{-5}$	$1.75 \cdot 10^{-5}$	$2.07 \cdot 10^{-5}$	$3.07 \cdot 10^{-5}$	$6.60 \cdot 10^{-4}$	$8.10 \cdot 10^{-4}$
30	$2.87 \cdot 10^{-5}$	$2.82 \cdot 10^{-5}$	$3.11 \cdot 10^{-6}$	$4.30 \cdot 10^{-5}$	$6.60 \cdot 10^{-5}$	$1.20 \cdot 10^{-4}$	$1.47 \cdot 10^{-4}$
50	$5.28 \cdot 10^{-5}$	$5.46 \cdot 10^{-5}$	$8.20 \cdot 10^{-5}$	$1.10 \cdot 10^{-4}$	$1.57 \cdot 10^{-4}$	$2.38 \cdot 10^{-4}$	$2.85 \cdot 10^{-4}$
100	$1.10 \cdot 10^{-4}$	$1.82 \cdot 10^{-4}$	$2.70 \cdot 10^{-4}$	$3.30 \cdot 10^{-4}$	$3.94 \cdot 10^{-4}$	$5.32 \cdot 10^{-4}$	$6.19 \cdot 10^{-4}$

Photon energy [MeV]	$_{26}$Fe	$_{29}$Cu	$_{42}$Mo	$_{50}$Sn	$_{74}$W	$_{82}$Pb	$_{92}$U
1.022	0	0	0	0	0	0	0
1.5	$5.0 \cdot 10^{-7}$	$6.0 \cdot 10^{-7}$	$8.0 \cdot 10^{-7}$	$9.0 \cdot 10^{-7}$	$1.2 \cdot 10^{-6}$	$1.3 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$
2	$1.1 \cdot 10^{-6}$	$1.3 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$2.8 \cdot 10^{-6}$	$2.8 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$
3	$2.9 \cdot 10^{-6}$	$3.2 \cdot 10^{-6}$	$4.3 \cdot 10^{-6}$	$4.9 \cdot 10^{-6}$	$6.1 \cdot 10^{-6}$	$6.4 \cdot 10^{-6}$	$6.8 \cdot 10^{-6}$
5	$8.0 \cdot 10^{-6}$	$8.6 \cdot 10^{-6}$	$1.11 \cdot 10^{-5}$	$1.25 \cdot 10^{-5}$	$1.57 \cdot 10^{-5}$	$1.67 \cdot 10^{-5}$	$1.79 \cdot 10^{-5}$
10	$3.05 \cdot 10^{-5}$	$3.17 \cdot 10^{-5}$	$3.85 \cdot 10^{-5}$	$4.32 \cdot 10^{-5}$	$5.40 \cdot 10^{-5}$	$5.65 \cdot 10^{-4}$	$5.91 \cdot 10^{-5}$
20	$9.10 \cdot 10^{-5}$	$9.43 \cdot 10^{-5}$	$1.14 \cdot 10^{-4}$	$1.24 \cdot 10^{-4}$	$1.50 \cdot 10^{-4}$	$1.56 \cdot 10^{-4}$	$1.66 \cdot 10^{-4}$
30	$1.64 \cdot 10^{-4}$	$1.68 \cdot 10^{-4}$	$1.98 \cdot 10^{-4}$	$2.17 \cdot 10^{-4}$	$2.55 \cdot 10^{-4}$	$2.66 \cdot 10^{-4}$	$2.76 \cdot 10^{-4}$
50	$3.11 \cdot 10^{-4}$	$3.20 \cdot 10^{-4}$	$3.73 \cdot 10^{-4}$	$4.00 \cdot 10^{-4}$	$4.59 \cdot 10^{-4}$	$4.78 \cdot 10^{-4}$	$4.96 \cdot 10^{-4}$
100	$6.64 \cdot 10^{-4}$	$6.76 \cdot 10^{-4}$	$7.76 \cdot 10^{-4}$	$8.20 \cdot 10^{-4}$	$9.20 \cdot 10^{-4}$	$9.41 \cdot 10^{-4}$	$9.74 \cdot 10^{-4}$

action cross sections σ_{tot} which agree with those in table 1.–4 within 5 percent.

This differential Bethe-Heitler Born-approximate cross section, without the high energy approximation and with screening disregarded, has been integrated analytically by Racah [1934, 1936] and Jost, Luttinger, and Slotnick [1950], but the resulting expression contains double and single integrals over elliptic functions. Recently Maximon [1968] has derived two series expansions for this expression, which he integrated to give the total cross section κ_n^{BH}(Born, unscreened). The resulting two series, which converge rapidly at low and high energies, respectively, are:

(a) For $E \leqslant 2$ MeV:

$$\kappa_n^{BH}(\text{Born, unscreened}) = \frac{Z^2 r_e^2}{137} \cdot \frac{2\pi}{3} \cdot \left(\frac{k-2}{k}\right)^3$$

$$\times \left[1 + \frac{1}{2}\rho + \frac{23}{40}\rho^2 + \frac{11}{60}\rho^3 + \frac{29}{960}\rho^4 + \cdot\cdot\cdot\right] \qquad (2.–34)$$

where

$$\rho = \frac{2k-4}{2+k+2\sqrt{2k}} \qquad (2.–35)$$

(b) For $E \geqslant 2$ MeV:

$$\kappa_n^{BH}(\text{Born, unscreened}) = \frac{Z^2 r_e^2}{137} \left\{ \frac{28}{9} \ln(2k) - \frac{218}{27} \right.$$

$$+ \left(\frac{2}{k}\right)^2 \left[6 \ln(2k) - \frac{7}{2} + \frac{2}{3} \ln^3(2k) - \ln^2(2k) \right.$$

$$\left. - \frac{1}{3}\pi^2 \ln(2k) + 2\zeta(3) + \frac{\pi^2}{6} \right]$$

$$- \left(\frac{2}{k}\right)^4 \left[\frac{3}{16} \ln(2k) + \frac{1}{8} \right]$$

$$\left. - \left(\frac{2}{k}\right)^6 \left[\frac{29}{9 \cdot 256} \ln(2k) - \frac{77}{27 \cdot 512} \right] + \cdot\cdot\cdot \right\} \qquad (2.–36)$$

where

$$\zeta(3) = \sum_{n=1}^{\infty} \frac{1}{n^3} = 1.2020569 \cdot\cdot\cdot . \qquad (2.–37)$$

These two expansions (2.–34) and (2.–36), using only the terms given here, provide values of κ_n^{BH}(Born, unscreened) accurate to within 0.01 per-

cent over the entire energy range from threshold to arbitrarily high energies.

In addition, Jost, Luttinger, and Slotnick [1950] have extended their derivation to the case of arbitrary screening. They obtained a formula differential in the momentum transfer which includes screening effects in terms of the atomic form factor $F(q, Z)$ and which can be numerically integrated to obtain the total cross section κ_n.

2.5.3. Pair Production in the Field of an Electron

This effect has a threshold of 4 mc^2 (=2.044 MeV) as required by the sharing, in this case, of the photon energy and momentum with the target electron as well as the created electron-positron pair. The resulting trajectories of the two electrons and the positron appear as a three-pronged track in a cloud chamber or photographic emulsion, hence the name "triplet production" often given to the process.

An exact theoretical treatment should include the following effects:

(1) atomic binding of the target electron,
(2) screening by the other atomic electrons and by the field of the nucleus,
(3) retardation which occurs when the atomic electron recoil velocity is not negligible in comparison with the velocity of light.
(4) the $\gamma - e$ interaction of the incident photon with the atomic electron (i.e., virtual Compton scattering in which the scattered photon gives rise to an electron-positron pair),
(5) exchange terms resulting from the indistinguishability of the two electrons, and
(6) the radiative corrections.

No one treatment has included all six of these effects, so numerical values are usually obtained from a combination of one or more of the following three principal theories, all of which employ the Born approximation.

Wheeler and Lamb [1939] used the high energy approximation and included the above effects (1) and (2). Ghizzetti [1947] and Borsellino[20] [1947] included only (3), but Suh and Bethe [1959] have shown that at high energies their neglect of exchange (5) is unimportant. Votruba [1948] included (3), (4) and (5), but his differential cross sections are so complex that until very recently the required integrations to obtain the total cross section have been done only crudely. However, Mork [1967] has now integrated the Votruba expressions numerically, and his results are shown in table 2.–14 in the form of an energy-dependent correction Δ (triplet) to be

TABLE 2.–14. *The Mork [1967] correction to the Borsellino-Ghizzetti κ_e result, obtained by numerical integration of the Votruba differential expressions.*

Photon energy [MeV]	Δ (triplet)
2.044	0.215
2.5	0.608
3	0.765
4	0.895
5	0.932
6	0.959
8	0.996
10	1.0

applied to the Borsellino-Ghizzetti result between threshold and 10 MeV.

Additional theoretical studies of triplet production have been made by Watson [1947], Nemirovsky [1947, 1948], Reyntjens [1957], Kopylov et al. [1964], Kaufman [1964], and Knasel [1968]. The most comprehensive survey of the theory is that of Joseph and Rohrlich [1958], and more recent results have been summarized by Gates et al. [1960, 1962], Koch [1964], Davisson [1965], and Olsen [1968].

In the present tabulation we use values of κ_e obtained by combining the Borsellino-Ghizzetti cross section κ_e^{BG} (using the Ghizzetti expansion which includes terms through k^{-7}), the Mork-Votruba correction Δ (triplet), the Wheeler-Lamb screened cross section κ_e^{WL} in the high-energy and Thomas-Fermi approximations, the Bethe-Heitler unscreened nuclear-field cross section κ_n^{BH}, and the Mork-Olsen radiative correction here assumed to have the value 1.01. From threshold to 10 MeV, where screening is negligible, we used the combination

$$\kappa_e = \kappa_e^{BH} \cdot \Delta(\text{triplet}) \cdot 1.01 \qquad (2.\text{–}38)$$

for the cross section per electron. At higher energies, as suggested by Mork, we used the combination

$$\kappa_e = \{\kappa_e^{WL} - [\kappa_n^{BH}({}_1\text{H}) - \kappa_e^{BG}]\} \cdot 1.01. \qquad (2.\text{–}39)$$

The Ghizzetti [1947] expansion for κ_e^{BG} is reproduced here for convenience:

$$\kappa_e^{BG} = \frac{r_e^2}{137}\left\{\frac{28}{9}\ln(2k) - \frac{218}{27}\right.$$
$$+\frac{1}{k}\left[-\frac{4}{3}\ln^3(2k) + 3\ln^2(2k)\right.$$
$$\left.-\frac{60+16a}{3}\ln(2k) + \frac{123+12a+16b}{3}\right]$$
$$+\left(\frac{1}{k}\right)^2\left[\frac{8}{3}\ln^3(2k) - 4\ln^2(2k)\right.$$
$$\left.+\frac{51+32a}{3}\ln(2k) - \frac{123+32a+64b}{6}\right]$$

[20] Mork has pointed out that the Borsellino result is identifiable as the leading terms of the series solution in eq (2.–40) by Ghizzetti [1947], and that the last Borsellino term should read −21.51, rather than +21.51, giving

$$\kappa_e\,(\text{Borsellino corrected}) = \frac{r_0^2}{137}\left\{\frac{28}{9}\ln(2k) - \frac{218}{27}\right.$$
$$\left.-\frac{1}{k}\left[\frac{4}{3}\ln^3(2k) - 3\ln^2(2k) + 6.84\ln(2k) - 21.51\right]\right\}$$

for the cross section per electron.

$$+\left(\frac{1}{k}\right)^3\left[\ln^2(2k)-\frac{53}{9}\ln(2k)-\frac{2915-288a}{216}\right]$$
$$+\left(\frac{1}{k}\right)^4\left[-\frac{49}{18}\ln(2k)-\frac{115}{432}\right]$$
$$+\left(\frac{1}{k}\right)^5\left[-\frac{77}{36}\ln(2k)+\frac{10831}{8640}\right]$$
$$+\left(\frac{1}{k}\right)^6\left[-\frac{641}{300}\ln(2k)+\frac{64573}{36000}\right]$$
$$+\left(\frac{1}{k}\right)^7\left[-\frac{4423}{1800}\ln(2k)+\frac{394979}{216000}\right]$$
$$+\ldots\Big\} \qquad (2.\text{–}40)$$

in which the constants

$$a=-2.46740 \text{ and}$$
$$b=-1.80310$$

are evaluations of definite integrals over a series expansion given by Ghizzetti. In addition, to make the results join smoothly and to correct for the Wheeler-Lamb high-energy approximation, we multiplied the results from eq (2.–39) by the ratio of these two results for hydrogen. This ratio [eq (2.–38) divided by eq (2.–39)] varies from 0.857 at 10 MeV to 0.997 at 100 MeV.

Values of κ_e from eqs (2.–38) and (–39), given explicitly in the tables in section 3, are also given in table 2.–15 in terms of the scaled ratio

$$\eta=Z\cdot(\kappa_e/\kappa_n) \qquad (2.\text{–}41)$$

for purposes of interpolation. The total pair production cross section can thus be reconstructed from tables 2.–10 and –15 as

$$\kappa=\kappa_n+\kappa_e=Z(Z+\eta)(\kappa_n/Z^2). \qquad (2.\text{–}42)$$

The values in table 2.–15 can be represented to within 5 percent from 10 to 100 MeV and within ±2 percent from 20 to 80 MeV by the empirical formula

$$\eta\approx\frac{3+a}{9}\ln\left(\frac{k}{2}\right)-0.00635\ln^3\left(\frac{k}{2}\right), \qquad (2.\text{–}43)$$

in which

$$a=Z/137,$$

TABLE 2.–15. *Values of $\eta=Z\cdot(\kappa_e/\kappa_n)$ relating the triplet cross section κ_e to that for nuclear-field pair production.*

Here, κ_e is the Borsellino [1947]-Ghizzetti [1947] unscreened result corrected for exchange and for $\gamma-e$ interaction near threshold by Mork [1967], for screening using the Wheeler-Lamb [1939] results, and includes a radiative correction factor of 1.01. Using table 2.–10, $\kappa(\text{total})=Z(Z+\eta)(\kappa_n/Z^2)$. For explicit values of κ_e up to 100 GeV, see tables in section 3.

Photon energy [MeV]	$_1$H	$_6$C	$_{13}$Al	$_{20}$Ca	$_{26}$Fe	$_{29}$Cu
	$\eta=Z\cdot(\kappa_e/\kappa_n)$					
2.044	0	0	0	0	0	0
3	0.0786	0.0787	0.0785	0.0781	0.0775	0.0773
4	0.199	0.200	0.199	0.199	0.199	0.199
5	0.292	0.292	0.293	0.293	0.294	0.294
10	0.543	0.545	0.550	0.555	0.559	0.562
20	0.707	0.711	0.721	0.729	0.737	0.741
30	0.779	0.787	0.801	0.811	0.819	0.820
50	0.849	0.868	0.883	0.888	0.890	0.891
100	0.920	0.956	0.963	0.966	0.968	0.968

Photon energy [MeV]	$_{42}$Mo	$_{50}$Sn	$_{74}$W	$_{82}$Pb	$_{92}$U	
	$\eta=Z\cdot(\kappa_e/\kappa_n)$					
2.044	0	0	0	0	0	
3	0.0755	0.0742	0.0700	0.0687	0.0669	
4	0.198	0.197	0.194	0.193	0.191	
5	0.295	0.296	0.298	0.299	0.300	
10	0.575	0.586	0.624	0.639	0.658	
20	0.761	0.773	0.819	0.837	0.861	
30	0.833	0.844	0.886	0.901	0.923	
50	0.903	0.912	0.954	0.973	0.994	
100	0.983	0.994	1.034	1.048	1.068	

and k is the photon energy in mc^2 units. Below 10 MeV, κ_e is less than 2 percent of σ_{tot}, and experimental estimates (see, for example, the recent results of Frei, Staub, and Stüssi [1964]) still contain uncertainties too large for confirmation of present theory.

2.6. Photonuclear Absorption

This effect consists of nuclear interactions initiated by the absorption of a photon. The most likely result of such an interaction is the emission of a single neutron, but one must also consider the emission of charged particles, gamma rays, or more than one neutron. Available experimental and theoretical information on such interactions is discussed in review articles by DeSabbata [1957, 1959], Levinger [1960], Fuller and Hayward [1962], Hayward [1963], Brenig [1965], and Danos and Fuller [1965].

The most characteristic feature of the cross section for nuclear absorption of photons is the "giant resonance." This is a broad peak in the absorption cross section centered at about 24 MeV for light nuclei, decreasing in energy with increasing mass number to about 12 MeV for the heaviest stable nuclei. The width "Γ" (energy difference between the points at which the cross section drops to one half its maximum value) varies from about 3 MeV to 9 MeV depending on the detailed properties of individual nuclei.

When studied with finer resolution the gross "resonance" is found to have considerable substructure. A prominent feature of this sub-structure, for nuclei having large permanent deformations, is a splitting of the giant resonance into two main peaks. In general, those nuclei having either large permanent deformations or large "dynamic deformations" (resulting from the vibrational nature of the nuclear ground state) have their giant resonances spread over the widest energy range.

Table 2.–16 gives the gross parameters of the giant resonance for a representative group of nuclei throughout the periodic table. From these parameters the giant resonance can be approximately reconstructed by assuming that it has the shape of a Lorentz line (see, e.g., Fuller and Hayward [1962], eg. (2.5), p. 117):

$$\sigma_{\text{ph. n.}}(E) \approx \sigma_0 \frac{E^2\Gamma^2}{(E_0{}^2 - E^2) + E^2\Gamma^2}. \tag{2.–44}$$

As indicated in table 2.–16, the magnitude of the photonuclear absorption cross section, even at the resonance peak energy, E_0, is small in comparison with the sum of the competing "electronic" cross sections discussed in sections 2.3 to 2.5, and in no case contributes more than 10 percent to the total cross section. However, photonuclear absorption can be of considerable importance in shielding and irradiation technology whenever photon energies are present which exceed reaction threshold energies such as those indicated in table 2.–16.

In shielding technology (see, e.g., NBS Handbook 97 [1964] and Hubbell and Spencer [1964]) nuclear absorption of photons is important because neutrons are produced in a large fraction of the reactions (about 40 to 100 percent probability depending on the photon energy and the mass number of the particular nucleus). These neutrons are usually far more penetrating than the incident photons. Of importance in irradiation technology (see, e.g.,

TABLE 2.–16. *Photonuclear giant resonance cross section parameters.*[1]

Nucleus	Threshold energies		E_0, energy at $\sigma_{\text{ph. n.}}$ peak	σ_0, value of $\sigma_{\text{ph. n.}}$ at peak	Γ, peak width at half-max.	Percent of "electronic" cross section at E_0	Refs.[2]
	(γ, n)	(γ, p)					
	MeV	*MeV*	*MeV*	*b/atom*	*MeV*	%	
^{12}C	18.7	16.0	[3] 23.	[4] 0.018	3.6	5.9	63 Bu 3
^{27}Al	13.1	8.3	[3] 21.5	[4] .038	9.0	3.9	64 Do 2
^{40}Ca	15.7	8.3	[3] 20.5	[4] .100	4.5	5.2	66 Do 2
^{63}Cu	10.8	6.1	17.0	[5] .070	8.0	2.0	64 Fu 1
^{90}Zr	12.0	8.4	17.0	[5] .180	4.5	3.0	67 Be 2
^{127}I	9.1	6.2	15.2	[5] .210	5.7	2.3	66 Br 1
^{165}Ho	8.0	6.1	[3] 14.0	[6] .220	8.5	1.7	65 Am 1
^{181}Ta	7.6	6.2	[3] 14.0	[6] .280	6.5	1.8	63 Br 1
^{208}Pb	7.4	8.0	13.6	[5] .495	3.8	2.7	64 Ha 2
^{235}U	6.1	7.6	[3] 12.2	[7] .500	7.0	2.4	64 Bo 3

[1] This table was supplied by E. G. Fuller.

[2] References (as given in the Photonuclear Data Index):

63 Br 1 Bramblett, R. L., Caldwell, J. T., Auchampaugh, G. F., Fultz S. C.; Phys. Rev. **129**, 2723 (1963).

63 Bu 3 Burgov, N. A., Danilyan, G. V., Dolbilkin, B. S., Lazareva, L. E., Nikolaev, F. A.; Zhur. Eksp. i Teoret. Fiz. **45**, 1693 (1963); Soviet Phys. JETP **18**, 1159 (1964).

64 Bo 3 Bowman, C. D., Auchampaugh, G. F., Fultz, S. C.; Phys. Rev. **133**, B676 (1964).

64 Do 2 Dolbilkin, B. S., Zapevalov, V. A., Korin, V. I., Lazareva, L. E., Nikolaev, F. A.; PICNS–64 1060 (1964).

64 Fu 1 Fultz, S. C., Bramblett, R. L., Caldwell, J. T., Harvey, R. R.: Phys. Rev. **133**, B1149 (1964).

64 Ha 2 Harvey, R. R., Caldwell, J. T., Bramblett, R. L., Fultz, S. C.; Phys. Rev. **136**, B126–131 (1964).

65 Am 1 Ambler, E., Fuller, E. G., Marshak, H.; Phys. Rev. **138**, B117 (1965).

66 Br 1 Bramblett, R. L., Caldwell, J. T., Berman, B. L., Harvey, R. R., Fultz, S. C.; Phys. Rev. **148**, B1198 (1966).

66 Do 2 Dolbilkin, B. S., Zapevalov, V. A., Korin, V. I., Lazareva, L. E., Nikolaev, F. A.; Izv. Akad. Nauk fiz. **30**, 349 (1966); Bull. Acad. Sci. USSR—Phys. **30**, 354 (1966).

67 Be 2 Berman, B. L., Caldwell, J. T., Harvey, R. R., Kelly, M. A., Bramblett, R. L., Fultz, S. C.; Phys. Rev. **162**, 1098 (1967).

[3] Cross section has structure. Energy given is approximate mean energy for photon absorption.

[4] Total nuclear absorption cross section at E_0.

[5] Maximum absorption cross section resulting in production of neutrons. For these nuclei this is a good approximation to the total nuclear absorption cross section.

[6] Deformed nuclei. Absorption cross section has two peaks. Comments under footnote 5 apply.

[7] Includes photofission cross section. Comments under footnotes 5 and 6 apply.

Manowitz et al. [1964] and DeProost et al. [1966]) as well as in shielding is the radioactivity which results from the photodisintegration of the nucleus in which the photon was absorbed or from the capture in other nuclei of the reaction products.

An initial attempt at a systematic photonuclear cross section compilation (in the form of graphs) has been made by Hunt et al. [1963] for use in food irradiator design studies. Parameters describing gross features of measured cross sections for photonuclear reactions have been tabulated by Goryachev [1964].

However, the best source of data for individual nuclei is at present the technical literature. Available data in the literature can be located by means of the NBS Photonuclear Data Index (Baggett et al. [1966] and Collins et al. [1967]) which is an annotated index and bibliography of references containing experimental data on photonuclear reactions. Each index entry gives specific quantitative data about the type of information available in each reference. The source of data used to compile this index is the NBS Photonuclear Data File. This file consists of data sheets containing abstracts of the significant data (both numerical and graphical) from each reference. These data sheets, as well as a reprint collection of all references abstracted, are on deposit at the Photonuclear Data Center at the National Bureau of Standards.

3. Tabulation of Cross Sections for Elements and Compounds

This section contains photon interaction cross sections and attenuation coefficients as described in sections 1 and 2. The data are presented by element, following the format of White-Grodstein [1957] and Davisson [1965] except that total cross sections are given in barns/atom in addition to the mass attenuation coefficient in cm²/g. Similar data (all in cm²/g) for some compounds and mixtures of interest in dosimetry (Evans [1968]) have been added.

In tables 3.–1 to 3.–23 the first column lists the photon energy in MeV. In this and in other columns the sign and following two digits at the end of each entry indicate the power of ten by which the preceding part of the entry is to be multiplied. A pair of successive identical energies, the second of which is preceded by K, L_1, L_2, or L_3, marks the presence of an "absorption edge" discontinuity in the photoelectric and total cross section columns.

The second column, labeled "scattering, with coherent," is the sum $(\sigma_C{}^{BD}+\sigma_R)$ of the Compton (incoherent) collision cross section corrected for electron binding and the Rayleigh (coherent) scattering cross section. This sum is based on values calculated by Storm and Israel [1967] (see sec. 2.4.2). The third column, labeled "scattering, without coherent," is the free-electron Compton collision cross section $(Z\times\sigma_C)$ [b/atom] where σ_C, including the Mork [1968] radiative and double-Compton corrections $\Delta\sigma_C^M$, is given in table 2.–8.

The fourth column, labeled "photoelectric," is the photoeffect cross section τ_{pe} derived from experimental and theoretical values by procedures described in section 2.3. The fifth column, labeled "pair production in field of nucleus," contains values of κ_n from eq (2.–31), and the sixth column, labeled "pair production in field of electrons," contains values of κ_e from eqs (2.–38) and (2.–39).

The seventh and eighth columns, labeled "total, with coherent" and "total, without coherent," are sums σ_{tot} over columns 2, 4, 5, and 6, and over columns 3, 4, 5, and 6, respectively. The conversion factor at the bottom of each page (also in table 1.–1) has been used to convert the total cross section values (b/atom) in columns 7 and 8 into the corresponding mass attenuation coefficients μ/ρ(cm²/g) in columns 9 and 10. Values of μ/ρ in the last column are identical with those in table 1.–4. Estimates of uncertainties for various ranges of E and Z are given in section 1.4.

Tables 3.–24 to 3.–36 for compounds and mixtures were derived from values in tables 3.–1 to 3.–23 using eq (1.–6) and the fractions-by-weight w_i in table 1.–3. Possible errors from use of the "mixture rule" as employed here are discussed in the last paragraph of section 1.3.

Table 3.—1. HYDROGEN, Z=1

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00—02	6.39—01	6.40—01	4.57—03			6.44—01	6.45—01	3.85—01	3.85—01
1.50—02	6.28—01	6.29—01	1.13—03			6.30—01	6.30—01	3.76—01	3.76—01
2.00—02	6.17—01	6.18—01	4.19—04			6.18—01	6.18—01	3.69—01	3.69—01
3.00—02		5.97—01	1.03—04				5.98—01		3.57—01
4.00—02		5.79—01	3.84—05				5.79—01		3.46—01
5.00—02		5.61—01	1.78—05				5.61—01		3.35—01
6.00—02		5.46—01	9.51—06				5.46—01		3.26—01
8.00—02		5.17—01	3.55—06				5.17—01		3.09—01
1.00—01		4.93—01	1.66—06				4.93—01		2.94—01
1.50—01		4.44—01	4.23—07				4.44—01		2.65—01
2.00—01		4.06—01	1.64—07				4.06—01		2.43—01
3.00—01		3.53—01	4.51—08				3.53—01		2.11—01
4.00—01		3.17—01	1.91—08				3.17—01		1.89—01
5.00—01		2.89—01	1.02—08				2.89—01		1.73—01
6.00—01		2.67—01	6.35—09				2.68—01		1.60—01
8.00—01		2.35—01	3.20—09				2.35—01		1.40—01
1.00+00		2.11—01	1.99—09				2.11—01		1.26—01
1.50+00		1.72—01	9.25—10	4.43—05			1.72—01		1.03—01
2.00+00		1.46—01	5.90—10	1.77—04			1.46—01		8.75—02
3.00+00		1.15—01	3.32—10	5.11—04	4.02—05		1.16—01		6.91—02
4.00+00		9.62—02	2.28—10	8.30—04	1.65—04		9.72—02		5.81—02
5.00+00		8.31—02	1.75—10	1.11—03	3.25—04		8.45—02		5.05—02
6.00+00		7.34—02	1.40—10	1.36—03	4.99—04		7.53—02		4.50—02
8.00+00		6.01—02	1.00—10	1.79—03	8.54—04		6.27—02		3.75—02
1.00+01		5.11—02	7.89—11	2.14—03	1.17—03		5.45—02		3.25—02
1.50+01		3.79—02		2.79—03	1.82—03		4.25—02		2.54—02
2.00+01		3.04—02		3.28—03	2.33—03		3.60—02		2.15—02
3.00+01		2.21—02		3.97—03	3.11—03		2.92—02		1.74—02
4.00+01		1.76—02		4.46—03	3.68—03		2.57—02		1.54—02
5.00+01		1.47—02		4.85—03	4.14—03		2.37—02		1.41—02
6.00+01		1.26—02		5.17—03	4.51—03		2.23—02		1.33—02
8.00+01		9.97—03		5.66—03	5.10—03		2.07—02		1.24—02
1.00+02		8.28—03		6.04—03	5.56—03		1.99—02		1.19—02
1.50+02		5.89—03		6.69—03	6.39—03		1.90—02		1.13—02
2.00+02		4.62—03		7.12—03	6.95—03		1.87—02		1.12—02
3.00+02		3.28—03		7.65—03	7.70—03		1.86—02		1.11—02
4.00+02		2.56—03		7.97—03	8.20—03		1.87—02		1.12—02
5.00+02		2.12—03		8.19—03	8.55—03		1.89—02		1.13—02
6.00+02		1.82—03		8.35—03	8.82—03		1.90—02		1.13—02
8.00+02		1.42—03		8.57—03	9.21—03		1.92—02		1.15—02
1.00+03		1.17—03		8.71—03	9.47—03		1.94—02		1.16—02
1.50+03		8.16—04		8.93—03	9.88—03		1.96—02		1.17—02
2.00+03		6.31—04		9.04—03	1.01—02		1.98—02		1.18—02
3.00+03		4.39—04		9.16—03	1.04—02		2.00—02		1.20—02
4.00+03		3.39—04		9.24—03	1.06—02		2.01—02		1.20—02
5.00+03		2.77—04		9.27—03	1.06—02		2.02—02		1.21—02
6.00+03		2.35—04		9.31—03	1.07—02		2.03—02		1.21—02
8.00+03		1.81—04		9.35—03	1.08—02		2.03—02		1.22—02
1.00+04		1.48—04		9.37—03	1.09—02		2.04—02		1.22—02
1.50+04		1.02—04		9.41—03	1.09—02		2.05—02		1.22—02
2.00+04		7.85—05		9.43—03	1.10—02		2.05—02		1.23—02
3.00+04		5.41—05		9.45—03	1.10—02		2.06—02		1.23—02
4.00+04		4.16—05		9.46—03	1.11—02		2.06—02		1.23—02
5.00+04		3.39—05		9.47—03	1.11—02		2.06—02		1.23—02
6.00+04		2.86—05		9.47—03	1.11—02		2.06—02		1.23—02
8.00+04		2.19—05		9.48—03	1.11—02		2.06—02		1.23—02
1.00+05		1.78—05		9.48—03	1.11—02		2.06—02		1.23—02

(b/atom) x .597500 = cm²/g

Table 3.−2. BERYLLIUM, Z=4

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00−02	3.42+00	2.56+00	5.46+00			8.88+00	8.02+00	5.93−01	5.36−01
1.50−02	3.01+00	2.52+00	1.49+00			4.50+00	4.01+00	3.00−01	2.68−01
2.00−02	2.78+00	2.47+00	6.12−01			3.39+00	3.08+00	2.27−01	2.06−01
3.00−02	2.54+00	2.39+00	1.68−01			2.70+00	2.56+00	1.81−01	1.71−01
4.00−02	2.40+00	2.31+00	6.45−02			2.47+00	2.38+00	1.65−01	1.59−01
5.00−02	2.31+00	2.25+00	3.06−02			2.34+00	2.28+00	1.56−01	1.52−01
6.00−02	2.23+00	2.18+00	1.67−02			2.24+00	2.20+00	1.50−01	1.47−01
8.00−02	2.09+00	2.07+00	6.44−03			2.10+00	2.08+00	1.40−01	1.39−01
1.00−01	1.99+00	1.97+00	3.04−03			1.99+00	1.97+00	1.33−01	1.32−01
1.50−01	1.78+00	1.77+00	8.01−04			1.78+00	1.77+00	1.19−01	1.19−01
2.00−01		1.63+00	3.15−04				1.63+00		1.09−01
3.00−01		1.41+00	8.83−05				1.41+00		9.45−02
4.00−01		1.27+00	3.76−05				1.27+00		8.47−02
5.00−01		1.16+00	2.01−05				1.16+00		7.73−02
6.00−01		1.07+00	1.26−05				1.07+00		7.15−02
8.00−01		9.40−01	6.32−06				9.41−01		6.29−02
1.00+00		8.45−01	3.91−06				8.46−01		5.65−02
1.50+00		6.87−01	1.83−06	7.10−04			6.88−01		4.60−02
2.00+00		5.86−01	1.16−06	2.84−03			5.89−01		3.94−02
3.00+00		4.61−01	6.55−07	8.17−03	1.61−04		4.70−01		3.14−02
4.00+00		3.85−01	4.48−07	1.33−02	6.61−04		3.99−01		2.66−02
5.00+00		3.32−01	3.44−07	1.78−02	1.30−03		3.51−01		2.35−02
6.00+00		2.94−01	2.75−07	2.18−02	2.00−03		3.17−01		2.12−02
8.00+00		2.40−01	1.97−07	2.86−02	3.42−03		2.72−01		1.82−02
1.00+01		2.05−01	1.55−07	3.41−02	4.67−03		2.43−01		1.63−02
1.50+01		1.51−01		4.46−02	7.27−03		2.03−01		1.36−02
2.00+01		1.21−01		5.23−02	9.34−03		1.83−01		1.22−02
3.00+01		8.85−02		6.32−02	1.24−02		1.64−01		1.10−02
4.00+01		7.03−02		7.09−02	1.47−02		1.56−01		1.04−02
5.00+01		5.87−02		7.67−02	1.66−02		1.52−01		1.02−02
6.00+01		5.06−02		8.12−02	1.80−02		1.50−01		1.00−02
8.00+01		3.99−02		8.81−02	2.04−02		1.48−01		9.91−03
1.00+02		3.31−02		9.31−02	2.22−02		1.48−01		9.92−03
1.50+02		2.36−02		1.01−01	2.53−02		1.50−01		1.00−02
2.00+02		1.85−02		1.07−01	2.74−02		1.52−01		1.02−02
3.00+02		1.31−02		1.13−01	3.02−02		1.56−01		1.04−02
4.00+02		1.03−02		1.17−01	3.20−02		1.59−01		1.06−02
5.00+02		8.49−03		1.20−01	3.33−02		1.61−01		1.08−02
6.00+02		7.27−03		1.21−01	3.43−02		1.63−01		1.09−02
8.00+02		5.68−03		1.24−01	3.59−02		1.66−01		1.11−02
1.00+03		4.67−03		1.26−01	3.69−02		1.68−01		1.12−02
1.50+03		3.26−03		1.28−01	3.87−02		1.70−01		1.14−02
2.00+03		2.52−03		1.30−01	3.98−02		1.72−01		1.15−02
3.00+03		1.76−03		1.31−01	4.11−02		1.74−01		1.16−02
4.00+03		1.35−03		1.32−01	4.19−02		1.75−01		1.17−02
5.00+03		1.11−03		1.33−01	4.24−02		1.76−01		1.18−02
6.00+03		9.40−04		1.33−01	4.28−02		1.77−01		1.18−02
8.00+03		7.24−04		1.34−01	4.32−02		1.77−01		1.19−02
1.00+04		5.91−04		1.34−01	4.35−02		1.78−01		1.19−02
1.50+04		4.08−04		1.34−01	4.38−02		1.79−01		1.19−02
2.00+04		3.14−04		1.35−01	4.40−02		1.79−01		1.20−02
3.00+04		2.17−04		1.35−01	4.42−02		1.79−01		1.20−02
4.00+04		1.66−04		1.35−01	4.43−02		1.79−01		1.20−02
5.00+04		1.35−04		1.35−01	4.44−02		1.79−01		1.20−02
6.00+04		1.14−04		1.35−01	4.44−02		1.80−01		1.20−02
8.00+04		8.78−05		1.35−01	4.44−02		1.80−01		1.20−02
1.00+05		7.14−05		1.35−01	4.45−02		1.80−01		1.20−02

(b/atom) x .066830 = cm²/g

Table 3.–3. BORON, Z=5

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	4.61+00	3.20+00	1.63+01			2.09+01	1.95+01	1.16+00	1.09+00
1.50–02	3.95+00	3.14+00	4.36+00			8.31+00	7.50+00	4.63–01	4.18–01
2.00–02	3.61+00	3.09+00	1.68+00			5.29+00	4.77+00	2.95–01	2.66–01
3.00–02	3.25+00	2.99+00	4.52–01			3.70+00	3.44+00	2.06–01	1.92–01
4.00–02	3.04+00	2.89+00	1.84–01			3.23+00	3.08+00	1.80–01	1.71–01
5.00–02	2.91+00	2.81+00	8.80–02			3.00+00	2.89+00	1.67–01	1.61–01
6.00–02	2.80+00	2.73+00	4.86–02			2.85+00	2.78+00	1.59–01	1.55–01
8.00–02	2.63+00	2.59+00	1.89–02			2.64+00	2.60+00	1.47–01	1.45–01
1.00–01	2.49+00	2.46+00	8.97–03			2.50+00	2.47+00	1.39–01	1.38–01
1.50–01	2.23+00	2.22+00	2.38–03			2.23+00	2.22+00	1.24–01	1.24–01
2.00–01	2.04+00	2.03+00	9.41–04			2.04+00	2.03+00	1.14–01	1.13–01
3.00–01	1.77+00	1.77+00	2.65–04			1.77+00	1.77+00	9.84–02	9.85–02
4.00–01		1.58+00	1.13–04				1.58+00		8.83–02
5.00–01		1.45+00	6.05–05				1.45+00		8.06–02
6.00–01		1.34+00	3.77–05				1.34+00		7.45–02
8.00–01		1.18+00	1.90–05				1.18+00		6.55–02
1.00+00		1.06+00	1.18–05				1.06+00		5.89–02
1.50+00		8.59–01	5.51–06	1.11–03			8.60–01		4.79–02
2.00+00		7.33–01	3.51–06	4.44–03			7.37–01		4.11–02
3.00+00		5.77–01	1.97–06	1.28–02	2.01–04		5.90–01		3.28–02
4.00+00		4.81–01	1.35–06	2.07–02	8.26–04		5.03–01		2.80–02
5.00+00		4.15–01	1.03–06	2.78–02	1.62–03		4.45–01		2.48–02
6.00+00		3.67–01	8.23–07	3.40–02	2.50–03		4.04–01		2.25–02
8.00+00		3.00–01	5.89–07	4.46–02	4.27–03		3.49–01		1.95–02
1.00+01		2.56–01	4.63–07	5.32–02	5.84–03		3.15–01		1.75–02
1.50+01		1.89–01		6.96–02	9.09–03		2.68–01		1.49–02
2.00+01		1.52–01		8.16–02	1.17–02		2.45–01		1.37–02
3.00+01		1.11–01		9.85–02	1.55–02		2.25–01		1.25–02
4.00+01		8.79–02		1.10–01	1.84–02		2.17–01		1.21–02
5.00+01		7.34–02		1.19–01	2.07–02		2.13–01		1.19–02
6.00+01		6.32–02		1.26–01	2.26–02		2.12–01		1.18–02
8.00+01		4.98–02		1.37–01	2.55–02		2.12–01		1.18–02
1.00+02		4.14–02		1.45–01	2.77–02		2.14–01		1.19–02
1.50+02		2.95–02		1.57–01	3.15–02		2.18–01		1.22–02
2.00+02		2.31–02		1.66–01	3.40–02		2.23–01		1.24–02
3.00+02		1.64–02		1.76–01	3.74–02		2.29–01		1.28–02
4.00+02		1.28–02		1.82–01	3.96–02		2.34–01		1.30–02
5.00+02		1.06–02		1.86–01	4.13–02		2.37–01		1.32–02
6.00+02		9.09–03		1.89–01	4.25–02		2.40–01		1.34–02
8.00+02		7.10–03		1.93–01	4.43–02		2.44–01		1.36–02
1.00+03		5.84–03		1.95–01	4.56–02		2.47–01		1.37–02
1.50+03		4.08–03		1.99–01	4.76–02		2.51–01		1.40–02
2.00+03		3.16–03		2.01–01	4.89–02		2.53–01		1.41–02
3.00+03		2.19–03		2.04–01	5.05–02		2.56–01		1.43–02
4.00+03		1.69–03		2.05–01	5.14–02		2.58–01		1.44–02
5.00+03		1.38–03		2.06–01	5.21–02		2.59–01		1.44–02
6.00+03		1.17–03		2.06–01	5.25–02		2.60–01		1.45–02
8.00+03		9.05–04		2.07–01	5.31–02		2.61–01		1.45–02
1.00+04		7.39–04		2.07–01	5.34–02		2.61–01		1.46–02
1.50+04		5.11–04		2.08–01	5.40–02		2.63–01		1.46–02
2.00+04		3.93–04		2.08–01	5.43–02		2.63–01		1.47–02
3.00+04		2.71–04		2.09–01	5.46–02		2.64–01		1.47–02
4.00+04		2.08–04		2.09–01	5.48–02		2.64–01		1.47–02
5.00+04		1.69–04		2.09–01	5.49–02		2.64–01		1.47–02
6.00+04		1.43–04		2.09–01	5.49–02		2.64–01		1.47–02
8.00+04		1.10–04		2.09–01	5.50–02		2.64–01		1.47–02
1.00+05		8.93–05		2.09–01	5.51–02		2.64–01		1.47–02

(b/atom) x .055710 = cm²/g

Table 3.–4. CARBON, Z=6

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	6.11+00	3.84+00	3.93+01			4.54+01	4.31+01	2.28+00	2.17+00
1.50–02	5.06+00	3.77+00	1.06+01			1.57+01	1.44+01	7.87–01	7.22–01
2.00–02	4.53+00	3.71+00	4.01+00			8.54+00	7.72+00	4.29–01	3.88–01
3.00–02	4.00+00	3.58+00	9.99–01			5.00+00	4.58+00	2.51–01	2.30–01
4.00–02	3.73+00	3.47+00	3.79–01			4.10+00	3.85+00	2.06–01	1.93–01
5.00–02	3.54+00	3.37+00	1.93–01			3.73+00	3.56+00	1.87–01	1.79–01
6.00–02	3.39+00	3.27+00	1.15–01			3.51+00	3.39+00	1.76–01	1.70–01
8.00–02	3.17+00	3.10+00	4.50–02			3.21+00	3.15+00	1.61–01	1.58–01
1.00–01	3.00+00	2.96+00	2.16–02			3.02+00	2.98+00	1.52–01	1.50–01
1.50–01	2.69+00	2.66+00	5.75–03			2.69+00	2.67+00	1.35–01	1.34–01
2.00–01	2.45+00	2.44+00	2.29–03			2.45+00	2.44+00	1.23–01	1.23–01
3.00–01	2.13+00	2.12+00	6.46–04			2.13+00	2.12+00	1.07–01	1.07–01
4.00–01	1.90+00	1.90+00	2.77–04			1.91+00	1.90+00	9.57–02	9.55–02
5.00–01		1.74+00	1.49–04				1.74+00		8.72–02
6.00–01		1.61+00	9.27–05				1.61+00		8.07–02
8.00–01		1.41+00	4.68–05				1.41+00		7.09–02
1.00+00		1.27+00	2.89–05				1.27+00		6.37–02
1.50+00		1.03+00	1.35–05	1.60–03			1.03+00		5.19–02
2.00+00		8.79–01	8.61–06	6.40–03			8.86–01		4.45–02
3.00+00		6.92–01	4.82–06	1.84–02	2.41–04		7.11–01		3.57–02
4.00+00		5.77–01	3.29–06	2.98–02	9.91–04		6.08–01		3.05–02
5.00+00		4.98–01	2.52–06	4.00–02	1.95–03		5.40–01		2.71–02
6.00+00		4.40–01	2.01–06	4.90–02	3.00–03		4.93–01		2.47–02
8.00+00		3.60–01	1.44–06	6.42–02	5.12–03		4.30–01		2.16–02
1.00+01		3.07–01	1.12–06	7.66–02	7.01–03		3.90–01		1.96–02
1.50+01		2.27–01		1.00–01	1.09–02		3.38–01		1.70–02
2.00+01		1.82–01		1.17–01	1.40–02		3.14–01		1.58–02
3.00+01		1.33–01		1.41–01	1.87–02		2.93–01		1.47–02
4.00+01		1.05–01		1.58–01	2.21–02		2.86–01		1.44–02
5.00+01		8.80–02		1.71–01	2.48–02		2.84–01		1.42–02
6.00+01		7.59–02		1.81–01	2.71–02		2.84–01		1.43–02
8.00+01		5.98–02		1.96–01	3.06–02		2.86–01		1.44–02
1.00+02		4.97–02		2.07–01	3.31–02		2.90–01		1.46–02
1.50+02		3.54–02		2.26–01	3.76–02		2.99–01		1.50–02
2.00+02		2.77–02		2.37–01	4.06–02		3.06–01		1.53–02
3.00+02		1.96–02		2.51–01	4.46–02		3.16–01		1.59–02
4.00+02		1.54–02		2.60–01	4.72–02		3.22–01		1.62–02
5.00+02		1.27–02		2.65–01	4.91–02		3.27–01		1.64–02
6.00+02		1.09–02		2.69–01	5.05–02		3.31–01		1.66–02
8.00+02		8.52–03		2.75–01	5.26–02		3.36–01		1.69–02
1.00+03		7.01–03		2.78–01	5.40–02		3.40–01		1.71–02
1.50+03		4.89–03		2.84–01	5.64–02		3.45–01		1.73–02
2.00+03		3.79–03		2.87–01	5.79–02		3.48–01		1.75–02
3.00+03		2.64–03		2.90–01	5.98–02		3.52–01		1.77–02
4.00+03		2.03–03		2.92–01	6.08–02		3.54–01		1.78–02
5.00+03		1.66–03		2.93–01	6.15–02		3.56–01		1.79–02
6.00+03		1.41–03		2.93–01	6.20–02		3.57–01		1.79–02
8.00+03		1.09–03		2.94–01	6.26–02		3.58–01		1.80–02
1.00+04		8.87–04		2.95–01	6.30–02		3.59–01		1.80–02
1.50+04		6.13–04		2.96–01	6.36–02		3.60–01		1.81–02
2.00+04		4.71–04		2.96–01	6.40–02		3.61–01		1.81–02
3.00+04		3.25–04		2.97–01	6.43–02		3.62–01		1.82–02
4.00+04		2.49–04		2.97–01	6.45–02		3.62–01		1.82–02
5.00+04		2.03–04		2.97–01	6.46–02		3.62–01		1.82–02
6.00+04		1.72–04		2.97–01	6.47–02		3.62–01		1.82–02
8.00+04		1.32–04		2.98–01	6.48–02		3.63–01		1.82–02
1.00+05		1.07–04		2.98–01	6.49–02		3.63–01		1.82–02

(b/atom) x .050240 = cm²/g

Table 3.–5. NITROGEN, Z=7

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	8.03+00	4.48+00	7.86+01			8.66+01	8.31+01	3.73+00	3.57+00
1.50–02	6.38+00	4.40+00	2.10+01			2.74+01	2.54+01	1.18+00	1.09+00
2.00–02	5.60+00	4.33+00	8.26+00			1.39+01	1.26+01	5.96–01	5.41–01
3.00–02	4.83+00	4.18+00	2.23+00			7.06+00	6.41+00	3.04–01	2.76–01
4.00–02	4.44+00	4.05+00	8.78–01			5.31+00	4.93+00	2.29–01	2.12–01
5.00–02	4.18+00	3.93+00	4.25–01			4.61+00	4.35+00	1.98–01	1.87–01
6.00–02	4.00+00	3.82+00	2.38–01			4.24+00	4.06+00	1.82–01	1.74–01
8.00–02	3.73+00	3.62+00	9.40–02			3.82+00	3.72+00	1.64–01	1.60–01
1.00–01	3.52+00	3.45+00	4.54–02			3.56+00	3.49+00	1.53–01	1.50–01
1.50–01	3.13+00	3.11+00	1.22–02			3.15+00	3.12+00	1.35–01	1.34–01
2.00–01	2.86+00	2.85+00	4.85–03			2.86+00	2.85+00	1.23–01	1.23–01
3.00–01	2.48+00	2.48+00	1.38–03			2.49+00	2.48+00	1.07–01	1.06–01
4.00–01		2.22+00	5.89–04				2.22+00		9.54–02
5.00–01		2.03+00	3.16–04				2.03+00		8.71–02
6.00–01		1.87+00	1.97–04				1.87+00		8.05–02
8.00–01		1.65+00	9.94–05				1.65+00		7.08–02
1.00+00		1.48+00	6.15–05				1.48+00		6.36–02
1.50+00		1.20+00	2.88–05	2.19–03			1.21+00		5.18–02
2.00+00		1.03+00	1.84–05	8.71–03			1.03+00		4.45–02
3.00+00		8.07–01	1.03–05	2.50–02	2.82–04		8.33–01		3.58–02
4.00+00		6.73–01	6.99–06	4.06–02	1.16–03		7.15–01		3.07–02
5.00+00		5.81–01	5.36–06	5.44–02	2.27–03		6.38–01		2.74–02
6.00+00		5.14–01	4.27–06	6.67–02	3.50–03		5.84–01		2.51–02
8.00+00		4.20–01	3.06–06	8.73–02	5.98–03		5.14–01		2.21–02
1.00+01		3.58–01	2.39–06	1.04–01	8.17–03		4.70–01		2.02–02
1.50+01		2.65–01		1.36–01	1.27–02		4.14–01		1.78–02
2.00+01		2.13–01		1.59–01	1.63–02		3.88–01		1.67–02
3.00+01		1.55–01		1.92–01	2.18–02		3.68–01		1.58–02
4.00+01		1.23–01		2.14–01	2.58–02		3.63–01		1.56–02
5.00+01		1.03–01		2.32–01	2.90–02		3.63–01		1.56–02
6.00+01		8.85–02		2.45–01	3.16–02		3.65–01		1.57–02
8.00+01		6.98–02		2.66–01	3.56–02		3.71–01		1.60–02
1.00+02		5.97–02		2.81–01	3.85–02		3.79–01		1.63–02
1.50+02		4.13–02		3.06–01	4.37–02		3.91–01		1.68–02
2.00+02		3.23–02		3.21–01	4.71–02		4.01–01		1.72–02
3.00+02		2.29–02		3.40–01	5.17–02		4.14–01		1.78–02
4.00+02		1.79–02		3.51–01	5.47–02		4.23–01		1.82–02
5.00+02		1.49–02		3.58–01	5.68–02		4.30–01		1.85–02
6.00+02		1.27–02		3.63–01	5.84–02		4.35–01		1.87–02
8.00+02		9.94–03		3.70–01	6.08–02		4.41–01		1.90–02
1.00+03		8.18–03		3.75–01	6.24–02		4.46–01		1.92–02
1.50+03		5.71–03		3.82–01	6.51–02		4.53–01		1.95–02
2.00+03		4.42–03		3.86–01	6.68–02		4.57–01		1.96–02
3.00+03		3.07–03		3.90–01	6.89–02		4.62–01		1.99–02
4.00+03		2.37–03		3.92–01	7.00–02		4.64–01		2.00–02
5.00+03		1.94–03		3.93–01	7.07–02		4.66–01		2.00–02
6.00+03		1.64–03		3.94–01	7.13–02		4.67–01		2.01–02
8.00+03		1.27–03		3.95–01	7.20–02		4.69–01		2.02–02
1.00+04		1.03–03		3.96–01	7.24–02		4.70–01		2.02–02
1.50+04		7.15–04		3.97–01	7.31–02		4.71–01		2.03–02
2.00+04		5.50–04		3.98–01	7.34–02		4.72–01		2.03–02
3.00+04		3.79–04		3.99–01	7.38–02		4.73–01		2.03–02
4.00+04		2.91–04		3.99–01	7.40–02		4.73–01		2.03–02
5.00+04		2.37–04		3.99–01	7.41–02		4.73–01		2.04–02
6.00+04		2.00–04		3.99–01	7.42–02		4.74–01		2.04–02
8.00+04		1.54–04		3.99–01	7.43–02		4.74–01		2.04–02
1.00+05		1.25–04		3.99–01	7.43–02		4.74–01		2.04–02

(b/atom) x .043000 = cm²/g

Table 3.–6. OXYGEN, Z=8

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	1.06+01	5.12+00	1.43+02			1.54+02	1.48+02	5.78+00	5.58+00
1.50–02	8.00+00	5.03+00	3.81+01			4.61+01	4.31+01	1.74+00	1.62+00
2.00–02	6.84+00	4.94+00	1.51+01			2.19+01	2.00+01	8.26–01	7.54–01
3.00–02	5.74+00	4.78+00	4.13+00			9.87+00	8.91+00	3.72–01	3.35–01
4.00–02	5.20+00	4.63+00	1.64+00			6.84+00	6.27+00	2.57–01	2.36–01
5.00–02	4.87+00	4.49+00	8.00–01			5.67+00	5.29+00	2.13–01	1.99–01
6.00–02	4.63+00	4.36+00	4.48–01			5.08+00	4.81+00	1.91–01	1.81–01
8.00–02	4.29+00	4.14+00	1.78–01			4.47+00	4.32+00	1.68–01	1.62–01
1.00–01	4.05+00	3.94+00	8.54–02			4.13+00	4.03+00	1.56–01	1.52–01
1.50–01	3.60+00	3.55+00	2.32–02			3.62+00	3.57+00	1.36–01	1.34–01
2.00–01	3.27+00	3.25+00	9.30–03			3.28+00	3.26+00	1.24–01	1.23–01
3.00–01	2.84+00	2.83+00	2.65–03			2.84+00	2.83+00	1.07–01	1.07–01
4.00–01	2.54+00	2.53+00	1.13–03			2.54+00	2.54+00	9.57–02	9.54–02
5.00–01	2.32+00	2.31+00	6.11–04			2.32+00	2.31+00	8.73–02	8.71–02
6.00–01	2.15+00	2.14+00	3.82–04			2.15+00	2.14+00	8.08–02	8.06–02
8.00–01		1.88+00	1.92–04				1.88+00		7.08–02
1.00+00		1.69+00	1.19–04				1.69+00		6.37–02
1.50+00		1.37+00	5.57–05	2.86–03			1.38+00		5.18–02
2.00+00		1.17+00	3.54–05	1.14–02			1.18+00		4.46–02
3.00+00		9.23–01	1.98–05	3.27–02	3.22–04		9.56–01		3.60–02
4.00+00		7.69–01	1.35–05	5.30–02	1.32–03		8.24–01		3.10–02
5.00+00		6.65–01	1.03–05	7.11–02	2.60–03		7.38–01		2.78–02
6.00+00		5.87–01	8.22–06	8.70–02	3.99–03		6.78–01		2.55–02
8.00+00		4.80–01	5.88–06	1.14–01	6.83–03		6.01–01		2.26–02
1.00+01		4.09–01	4.61–06	1.36–01	9.34–03		5.54–01		2.09–02
1.50+01		3.03–01		1.77–01	1.45–02		4.95–01		1.86–02
2.00+01		2.43–01		2.08–01	1.87–02		4.69–01		1.77–02
3.00+01		1.77–01		2.50–01	2.49–02		4.52–01		1.70–02
4.00+01		1.41–01		2.79–01	2.95–02		4.49–01		1.69–02
5.00+01		1.17–01		3.01–01	3.31–02		4.52–01		1.70–02
6.00+01		1.01–01		3.19–01	3.61–02		4.56–01		1.72–02
8.00+01		7.98–02		3.46–01	4.05–02		4.66–01		1.75–02
1.00+02		6.62–02		3.65–01	4.39–02		4.75–01		1.79–02
1.50+02		4.72–02		3.97–01	4.97–02		4.94–01		1.86–02
2.00+02		3.70–02		4.17–01	5.36–02		5.08–01		1.91–02
3.00+02		2.62–02		4.40–01	5.87–02		5.25–01		1.98–02
4.00+02		2.05–02		4.54–01	6.21–02		5.37–01		2.02–02
5.00+02		1.70–02		4.63–01	6.44–02		5.45–01		2.05–02
6.00+02		1.45–02		4.70–01	6.62–02		5.51–01		2.07–02
8.00+02		1.14–02		4.79–01	6.88–02		5.59–01		2.10–02
1.00+03		9.34–03		4.84–01	7.07–02		5.65–01		2.12–02
1.50+03		6.53–03		4.93–01	7.37–02		5.73–01		2.16–02
2.00+03		5.05–03		4.98–01	7.56–02		5.78–01		2.18–02
3.00+03		3.51–03		5.02–01	7.78–02		5.84–01		2.20–02
4.00+03		2.71–03		5.05–01	7.90–02		5.87–01		2.21–02
5.00+03		2.22–03		5.07–01	7.98–02		5.89–01		2.22–02
6.00+03		1.88–03		5.08–01	8.04–02		5.90–01		2.22–02
8.00+03		1.45–03		5.09–01	8.11–02		5.92–01		2.23–02
1.00+04		1.18–03		5.10–01	8.16–02		5.93–01		2.23–02
1.50+04		8.17–04		5.12–01	8.23–02		5.95–01		2.24–02
2.00+04		6.28–04		5.12–01	8.27–02		5.96–01		2.24–02
3.00+04		4.33–04		5.13–01	8.31–02		5.97–01		2.25–02
4.00+04		3.33–04		5.13–01	8.33–02		5.97–01		2.25–02
5.00+04		2.71–04		5.14–01	8.34–02		5.97–01		2.25–02
6.00+04		2.29–04		5.14–01	8.35–02		5.98–01		2.25–02
8.00+04		1.75–04		5.14–01	8.37–02		5.98–01		2.25–02
1.00+05		1.43–04		5.14–01	8.38–02		5.98–01		2.25–02

(b/atom) x .037640 = cm²/g

Table 3.–7. SODIUM, Z=11

Photon energy.	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	2.19+01	7.04+00	5.69+02			5.91+02	5.76+02	1.55+01	1.51+01
1.50–02	1.49+01	6.92+00	1.60+02			1.75+02	1.67+02	4.58+00	4.37+00
2.00–02	1.18+01	6.80+00	6.48+01			7.66+01	7.16+01	2.01+00	1.88+00
3.00–02	9.11+00	6.57+00	1.78+01			2.69+01	2.44+01	7.05–01	6.39–01
4.00–02	7.90+00	6.37+00	7.18+00			1.51+01	1.35+01	3.95–01	3.55–01
5.00–02	7.19+00	6.18+00	3.53+00			1.07+01	9.71+00	2.81–01	2.54–01
6.00–02	6.73+00	6.00+00	1.99+00			8.72+00	7.99+00	2.28–01	2.09–01
8.00–02	6.11+00	5.69+00	7.92–01			6.90+00	6.48+00	1.81–01	1.70–01
1.00–01	5.69+00	5.42+00	3.85–01			6.08+00	5.80+00	1.59–01	1.52–01
1.50–01	5.01+00	4.88+00	1.06–01			5.11+00	4.99+00	1.34–01	1.31–01
2.00–01	4.54+00	4.47+00	4.29–02			4.58+00	4.51+00	1.20–01	1.18–01
3.00–01	3.92+00	3.89+00	1.24–02			3.93+00	3.90+00	1.03–01	1.02–01
4.00–01	3.50+00	3.48+00	5.31–03			3.50+00	3.49+00	9.18–02	9.14–02
5.00–01	3.19+00	3.18+00	2.86–03			3.19+00	3.18+00	8.36–02	8.34–02
6.00–01	2.95+00	2.94+00	1.78–03			2.95+00	2.95+00	7.74–02	7.72–02
8.00–01		2.59+00	9.01–04				2.59+00		6.78–02
1.00+00		2.33+00	5.58–04				2.33+00		6.09–02
1.50+00		1.89+00	2.61–04	5.46–03			1.90+00		4.97–02
2.00+00		1.61+00	1.67–04	2.16–02			1.63+00		4.28–02
3.00+00		1.27+00	9.25–05	6.19–02	4.43–04		1.33+00		3.49–02
4.00+00		1.06+00	6.28–05	1.00–01	1.82–03		1.16+00		3.04–02
5.00+00		9.14–01	4.79–05	1.34–01	3.57–03		1.05+00		2.76–02
6.00+00		8.08–01	3.82–05	1.64–01	5.49–03		9.77–01		2.56–02
8.00+00		6.61–01	2.73–05	2.15–01	9.40–03		8.85–01		2.32–02
1.00+01		5.63–01	2.14–05	2.56–01	1.28–02		8.31–01		2.18–02
1.50+01		4.16–01		3.34–01	2.00–02		7.70–01		2.02–02
2.00+01		3.34–01		3.90–01	2.57–02		7.50–01		1.96–02
3.00+01		2.43–01		4.69–01	3.42–02		7.47–01		1.96–02
4.00+01		1.93–01		5.24–01	4.05–02		7.58–01		1.99–02
5.00+01		1.61–01		5.65–01	4.55–02		7.72–01		2.02–02
6.00+01		1.39–01		5.98–01	4.94–02		7.87–01		2.06–02
8.00+01		1.10–01		6.47–01	5.53–02		8.12–01		2.13–02
1.00+02		9.11–02		6.82–01	5.98–02		8.33–01		2.18–02
1.50+02		6.48–02		7.39–01	6.75–02		8.72–01		2.28–02
2.00+02		5.08–02		7.74–01	7.27–02		8.97–01		2.35–02
3.00+02		3.60–02		8.14–01	7.95–02		9.30–01		2.44–02
4.00+02		2.82–02		8.38–01	8.38–02		9.50–01		2.49–02
5.00+02		2.34–02		8.53–01	8.69–02		9.64–01		2.52–02
6.00+02		2.00–02		8.65–01	8.92–02		9.74–01		2.55–02
8.00+02		1.56–02		8.79–01	9.26–02		9.87–01		2.59–02
1.00+03		1.28–02		8.88–01	9.50–02		9.96–01		2.61–02
1.50+03		8.97–03		9.03–01	9.89–02		1.01+00		2.65–02
2.00+03		6.94–03		9.10–01	1.01–01		1.02+00		2.67–02
3.00+03		4.83–03		9.18–01	1.04–01		1.03+00		2.69–02
4.00+03		3.73–03		9.23–01	1.05–01		1.03+00		2.70–02
5.00+03		3.05–03		9.26–01	1.06–01		1.04+00		2.71–02
6.00+03		2.58–03		9.28–01	1.07–01		1.04+00		2.72–02
8.00+03		1.99–03		9.30–01	1.08–01		1.04+00		2.72–02
1.00+04		1.63–03		9.31–01	1.08–01		1.04+00		2.73–02
1.50+04		1.12–03		9.34–01	1.09–01		1.04+00		2.74–02
2.00+04		8.64–04		9.36–01	1.10–01		1.05+00		2.74–02
3.00+04		5.96–04		9.36–01	1.10–01		1.05+00		2.74–02
4.00+04		4.57–04		9.37–01	1.10–01		1.05+00		2.75–02
5.00+04		3.72–04		9.38–01	1.11–01		1.05+00		2.75–02
6.00+04		3.15–04		9.38–01	1.11–01		1.05+00		2.75–02
8.00+04		2.41–04		9.38–01	1.11–01		1.05+00		2.75–02
1.00+05		1.96–04		9.38–01	1.11–01		1.05+00		2.75–02

(b/atom) x .026200 = cm²/g

Table 3.-8. MAGNESIUM, Z=12

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00-02	2.60+01	7.68+00	8.13+02			8.39+02	8.21+02	2.08+01	2.03+01
1.50-02	1.75+01	7.55+00	2.34+02			2.52+02	2.42+02	6.23+00	5.98+00
2.00-02	1.37+01	7.41+00	9.60+01			1.10+02	1.03+02	2.72+00	2.56+00
3.00-02	1.03+01	7.17+00	2.67+01			3.70+01	3.39+01	9.18-01	8.39-01
4.00-02	8.87+00	6.94+00	1.07+01			1.96+01	1.76+01	4.85-01	4.37-01
5.00-02	8.02+00	6.74+00	5.28+00			1.33+01	1.20+01	3.29-01	2.98-01
6.00-02	7.46+00	6.55+00	2.97+00			1.04+01	9.52+00	2.58-01	2.36-01
8.00-02	6.73+00	6.21+00	1.19+00			7.92+00	7.40+00	1.96-01	1.83-01
1.00-01	6.25+00	5.91+00	5.81-01			6.83+00	6.49+00	1.69-01	1.61-01
1.50-01	5.48+00	5.32+00	1.60-01			5.64+00	5.48+00	1.40-01	1.36-01
2.00-01	4.96+00	4.88+00	6.48-02			5.03+00	4.94+00	1.25-01	1.22-01
3.00-01	4.28+00	4.24+00	1.87-02			4.30+00	4.26+00	1.06-01	1.06-01
4.00-01	3.82+00	3.80+00	8.08-03			3.83+00	3.81+00	9.49-02	9.44-02
5.00-01	3.48+00	3.47+00	4.35-03			3.49+00	3.48+00	8.64-02	8.61-02
6.00-01	3.22+00	3.21+00	2.72-03			3.22+00	3.21+00	7.97-02	7.96-02
8.00-01	2.83+00	2.82+00	1.37-03			2.83+00	2.82+00	7.01-02	6.99-02
1.00+00	2.54+00	2.54+00	8.50-04			2.54+00	2.54+00	6.28-02	6.29-02
1.50+00		2.06+00	3.99-04	6.52-03			2.07+00		5.12-02
2.00+00		1.76+00	2.53-04	2.58-02			1.79+00		4.42-02
3.00+00		1.38+00	1.40-04	7.36-02	4.83-04		1.46+00		3.61-02
4.00+00		1.15+00	9.53-05	1.19-01	1.98-03		1.28+00		3.16-02
5.00+00		9.97-01	7.27-05	1.60-01	3.89-03		1.16+00		2.87-02
6.00+00		8.81-01	5.79-05	1.95-01	5.99-03		1.08+00		2.68-02
8.00+00		7.21-01	4.14-05	2.55-01	1.02-02		9.86-01		2.44-02
1.00+01		6.14-01	3.23-05	3.04-01	1.40-02		9.32-01		2.31-02
1.50+01		4.54-01		3.96-01	2.18-02		8.73-01		2.16-02
2.00+01		3.65-01		4.63-01	2.80-02		8.56-01		2.12-02
3.00+01		2.66-01		5.57-01	3.73-02		8.60-01		2.13-02
4.00+01		2.11-01		6.22-01	4.42-02		8.77-01		2.17-02
5.00+01		1.76-01		6.71-01	4.95-02		8.97-01		2.22-02
6.00+01		1.52-01		7.10-01	5.37-02		9.15-01		2.27-02
8.00+01		1.20-01		7.67-01	6.02-02		9.47-01		2.35-02
1.00+02		9.93-02		8.09-01	6.50-02		9.73-01		2.41-02
1.50+02		7.07-02		8.76-01	7.34-02		1.02+00		2.53-02
2.00+02		5.54-02		9.16-01	7.91-02		1.05+00		2.60-02
3.00+02		3.93-02		9.64-01	8.63-02		1.09+00		2.70-02
4.00+02		3.08-02		9.91-01	9.10-02		1.11+00		2.76-02
5.00+02		2.55-02		1.01+00	9.43-02		1.13+00		2.80-02
6.00+02		2.18-02		1.02+00	9.67-02		1.14+00		2.83-02
8.00+02		1.70-02		1.04+00	1.00-01		1.16+00		2.87-02
1.00+03		1.40-02		1.05+00	1.03-01		1.17+00		2.90-02
1.50+03		9.79-03		1.07+00	1.07-01		1.18+00		2.93-02
2.00+03		7.58-03		1.08+00	1.10-01		1.19+00		2.96-02
3.00+03		5.27-03		1.09+00	1.12-01		1.20+00		2.98-02
4.00+03		4.07-03		1.09+00	1.14-01		1.21+00		3.00-02
5.00+03		3.33-03		1.10+00	1.15-01		1.21+00		3.01-02
6.00+03		2.82-03		1.10+00	1.16-01		1.22+00		3.02-02
8.00+03		2.17-03		1.10+00	1.17-01		1.22+00		3.02-02
1.00+04		1.77-03		1.10+00	1.17-01		1.22+00		3.03-02
1.50+04		1.23-03		1.11+00	1.18-01		1.23+00		3.03-02
2.00+04		9.42-04		1.11+00	1.18-01		1.23+00		3.04-02
3.00+04		6.50-04		1.11+00	1.19-01		1.23+00		3.04-02
4.00+04		4.99-04		1.11+00	1.19-01		1.23+00		3.05-02
5.00+04		4.06-04		1.11+00	1.19-01		1.23+00		3.05-02
6.00+04		3.43-04		1.11+00	1.20-01		1.23+00		3.05-02
8.00+04		2.63-04		1.11+00	1.20-01		1.23+00		3.05-02
1.00+05		2.14-04		1.11+00	1.20-01		1.23+00		3.05-02

(b/atom) x .024770 = cm²/g

Table 3.–9. ALUMINUM, Z=13

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	3.04+01	8.32+00	1.15+03			1.18+03	1.16+03	2.63+01	2.58+01
1.50–02	2.03+01	8.17+00	3.35+02			3.55+02	3.43+02	7.93+00	7.66+00
2.00–02	1.57+01	8.03+00	1.37+02			1.53+02	1.45+02	3.41+00	3.24+00
3.00–02	1.17+01	7.77+00	3.85+01			5.02+01	4.63+01	1.12+00	1.03+00
4.00–02	9.89+00	7.52+00	1.55+01			2.54+01	2.30+01	5.67–01	5.14–01
5.00–02	8.88+00	7.30+00	7.65+00			1.65+01	1.49+01	3.69–01	3.34–01
6.00–02	8.22+00	7.09+00	4.33+00			1.25+01	1.14+01	2.80–01	2.55–01
8.00–02	7.38+00	6.72+00	1.73+00			9.11+00	8.45+00	2.03–01	1.89–01
1.00–01	6.83+00	6.41+00	8.45–01			7.67+00	7.25+00	1.71–01	1.62–01
1.50–01	5.96+00	5.77+00	2.33–01			6.19+00	6.00+00	1.38–01	1.34–01
2.00–01	5.39+00	5.28+00	9.53–02			5.49+00	5.38+00	1.22–01	1.20–01
3.00–01	4.64+00	4.60+00	2.76–02			4.67+00	4.62+00	1.04–01	1.03–01
4.00–01	4.14+00	4.12+00	1.19–02			4.15+00	4.13+00	9.27–02	9.22–02
5.00–01	3.78+00	3.76+00	6.43–03			3.78+00	3.77+00	8.44–02	8.41–02
6.00–01	3.49+00	3.48+00	4.02–03			3.49+00	3.48+00	7.80–02	7.77–02
8.00–01	3.06+00	3.06+00	2.04–03			3.06+00	3.06+00	6.84–02	6.83–02
1.00+00	2.75+00	2.75+00	1.26–03			2.75+00	2.75+00	6.13–02	6.14–02
1.50+00		2.23+00	5.89–04	7.68–03			2.24+00		5.00–02
2.00+00		1.91+00	3.73–04	3.03–02			1.94+00		4.32–02
3.00+00		1.50+00	2.07–04	8.65–02	5.23–04		1.59+00		3.54–02
4.00+00		1.25+00	1.41–04	1.40–01	2.15–03		1.39+00		3.11–02
5.00+00		1.08+00	1.07–04	1.87–01	4.22–03		1.27+00		2.84–02
6.00+00		9.54–01	8.53–05	2.29–01	6.49–03		1.19+00		2.66–02
8.00+00		7.81–01	6.09–05	2.99–01	1.11–02		1.09+00		2.44–02
1.00+01		6.65–01	4.76–05	3.57–01	1.52–02		1.04+00		2.31–02
1.50+01		4.92–01		4.65–01	2.36–02		9.80–01		2.19–02
2.00+01		3.95–01		5.43–01	3.03–02		9.68–01		2.16–02
3.00+01		2.88–01		6.52–01	4.04–02		9.81–01		2.19–02
4.00+01		2.29–01		7.29–01	4.79–02		1.01+00		2.24–02
5.00+01		1.91–01		7.86–01	5.36–02		1.03+00		2.30–02
6.00+01		1.64–01		8.31–01	5.81–02		1.05+00		2.35–02
8.00+01		1.30–01		8.98–01	6.51–02		1.09+00		2.44–02
1.00+02		1.08–01		9.46–01	7.03–02		1.12+00		2.51–02
1.50+02		7.66–02		1.02+00	7.93–02		1.18+00		2.63–02
2.00+02		6.01–02		1.07+00	8.53–02		1.21+00		2.71–02
3.00+02		4.26–02		1.13+00	9.31–02		1.26+00		2.82–02
4.00+02		3.33–02		1.16+00	9.81–02		1.29+00		2.88–02
5.00+02		2.76–02		1.18+00	1.02–01		1.31+00		2.92–02
6.00+02		2.36–02		1.19+00	1.04–01		1.32+00		2.95–02
8.00+02		1.85–02		1.22+00	1.08–01		1.34+00		3.00–02
1.00+03		1.52–02		1.23+00	1.11–01		1.35+00		3.02–02
1.50+03		1.06–02		1.25+00	1.15–01		1.37+00		3.07–02
2.00+03		8.21–03		1.26+00	1.18–01		1.38+00		3.09–02
3.00+03		5.71–03		1.27+00	1.21–01		1.40+00		3.12–02
4.00+03		4.40–03		1.28+00	1.22–01		1.40+00		3.13–02
5.00+03		3.60–03		1.28+00	1.23–01		1.41+00		3.14–02
6.00+03		3.05–03		1.28+00	1.24–01		1.41+00		3.15–02
8.00+03		2.35–03		1.29+00	1.25–01		1.41+00		3.16–02
1.00+04		1.92–03		1.29+00	1.26–01		1.42+00		3.16–02
1.50+04		1.33–03		1.29+00	1.27–01		1.42+00		3.17–02
2.00+04		1.02–03		1.29+00	1.27–01		1.42+00		3.17–02
3.00+04		7.04–04		1.30+00	1.28–01		1.42+00		3.18–02
4.00+04		5.40–04		1.30+00	1.28–01		1.43+00		3.18–02
5.00+04		4.40–04		1.30+00	1.28–01		1.43+00		3.18–02
6.00+04		3.72–04		1.30+00	1.28–01		1.43+00		3.18–02
8.00+04		2.85–04		1.30+00	1.28–01		1.43+00		3.18–02
1.00+05		2.32–04		1.30+00	1.28–01		1.43+00		3.19–02

(b/atom) x .022320 = cm²/g

Table 3.-10. SILICON, Z=14

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm^2/g*	*cm^2/g*
1.00-02	3.50+01	8.97+00	1.56+03			1.59+03	1.57+03	3.42+01	3.36+01
1.50-02	2.34+01	8.80+00	4.56+02			4.79+02	4.65+02	1.03+01	9.97+00
2.00-02	1.78+01	8.65+00	1.87+02			2.05+02	1.96+02	4.39+00	4.19+00
3.00-02	1.31+01	8.36+00	5.29+01			6.60+01	6.13+01	1.41+00	1.31+00
4.00-02	1.10+01	8.10+00	2.15+01			3.25+01	2.96+01	6.96-01	6.35-01
5.00-02	9.79+00	7.86+00	1.06+01			2.04+01	1.85+01	4.37-01	3.96-01
6.00-02	9.01+00	7.64+00	6.00+00			1.50+01	1.36+01	3.22-01	2.92-01
8.00-02	8.04+00	7.24+00	2.42+00			1.05+01	9.66+00	2.24-01	2.07-01
1.00-01	7.41+00	6.90+00	1.19+00			8.60+00	8.09+00	1.84-01	1.73-01
1.50-01	6.44+00	6.21+00	3.29-01			6.77+00	6.54+00	1.45-01	1.40-01
2.00-01	5.82+00	5.69+00	1.34-01			5.96+00	5.82+00	1.28-01	1.25-01
3.00-01	5.01+00	4.95+00	3.91-02			5.05+00	4.99+00	1.08-01	1.07-01
4.00-01	4.47+00	4.43+00	1.69-02			4.49+00	4.45+00	9.62-02	9.54-02
5.00-01	4.07+00	4.05+00	9.15-03			4.08+00	4.06+00	8.75-02	8.70-02
6.00-01	3.76+00	3.75+00	5.72-03			3.77+00	3.75+00	8.08-02	8.05-02
8.00-01	3.29+00	3.29+00	2.89-03			3.30+00	3.29+00	7.07-02	7.06-02
1.00+00		2.96+00	1.79-03				2.96+00		6.35-02
1.50+00		2.40+00	8.36-04	8.94-03			2.41+00		5.18-02
2.00+00		2.05+00	5.30-04	3.52-02			2.09+00		4.48-02
3.00+00		1.61+00	2.93-04	1.00-01	5.63-04		1.72+00		3.68-02
4.00+00		1.35+00	1.99-04	1.62-01	2.31-03		1.51+00		3.24-02
5.00+00		1.16+00	1.42-04	2.17-01	4.54-03		1.38+00		2.97-02
6.00+00		1.03+00	1.21-04	2.67-01	6.99-03		1.30+00		2.79-02
8.00+00		8.41-01	8.61-05	3.47-01	1.20-02		1.20+00		2.57-02
1.00+01		7.16-01	6.74-05	4.13-01	1.63-02		1.15+00		2.46-02
1.50+01		5.30-01		5.38-01	2.55-02		1.09+00		2.34-02
2.00+01		4.25-01		6.28-01	3.27-02		1.09+00		2.33-02
3.00+01		3.10-01		7.55-01	4.35-02		1.11+00		2.38-02
4.00+01		2.46-01		8.43-01	5.16-02		1.14+00		2.45-02
5.00+01		2.05-01		9.13-01	5.76-02		1.18+00		2.52-02
6.00+01		1.77-01		9.61-01	6.25-02		1.20+00		2.57-02
8.00+01		1.40-01		1.04+00	6.99-02		1.25+00		2.67-02
1.00+02		1.16-01		1.09+00	7.55-02		1.28+00		2.75-02
1.50+02		8.25-02		1.18+00	8.51-02		1.35+00		2.89-02
2.00+02		6.47-02		1.24+00	9.16-02		1.39+00		2.99-02
3.00+02		4.58-02		1.30+00	9.98-02		1.45+00		3.10-02
4.00+02		3.59-02		1.34+00	1.05-01		1.48+00		3.17-02
5.00+02		2.97-02		1.36+00	1.09-01		1.50+00		3.22-02
6.00+02		2.55-02		1.38+00	1.12-01		1.52+00		3.25-02
8.00+02		1.99-02		1.40+00	1.16-01		1.54+00		3.30-02
1.00+03		1.63-02		1.42+00	1.19-01		1.55+00		3.33-02
1.50+03		1.14-02		1.44+00	1.23-01		1.58+00		3.38-02
2.00+03		8.84-03		1.45+00	1.26-01		1.59+00		3.41-02
3.00+03		6.15-03		1.47+00	1.29-01		1.60+00		3.44-02
4.00+03		4.74-03		1.47+00	1.31-01		1.61+00		3.45-02
5.00+03		3.88-03		1.48+00	1.32-01		1.61+00		3.46-02
6.00+03		3.29-03		1.48+00	1.33-01		1.62+00		3.47-02
8.00+03		2.53-03		1.49+00	1.34-01		1.62+00		3.48-02
1.00+04		2.07-03		1.49+00	1.34-01		1.63+00		3.48-02
1.50+04		1.43-03		1.49+00	1.35-01		1.63+00		3.49-02
2.00+04		1.10-03		1.49+00	1.36-01		1.63+00		3.50-02
3.00+04		7.58-04		1.50+00	1.36-01		1.63+00		3.50-02
4.00+04		5.82-04		1.50+00	1.37-01		1.64+00		3.51-02
5.00+04		4.74-04		1.50+00	1.37-01		1.64+00		3.51-02
6.00+04		4.01-04		1.50+00	1.37-01		1.64+00		3.51-02
8.00+04		3.07-04		1.50+00	1.37-01		1.64+00		3.51-02
1.00+05		2.50-04		1.50+00	1.37-01		1.64+00		3.51-02

(b/atom) x .021440 = cm^2/g

Table 3.–11. PHOSPHORUS, Z=15

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	3.99+01	9.61+00	2.06+03			2.10+03	2.07+03	4.08+01	4.02+01
1.50–02	2.66+01	9.43+00	6.10+02			6.37+02	6.19+02	1.24+01	1.20+01
2.00–02	2.02+01	9.27+00	2.53+02			2.73+02	2.62+02	5.31+00	5.10+00
3.00–02	1.46+01	8.96+00	7.10+01			8.56+01	8.00+01	1.66+00	1.55+00
4.00–02	1.21+01	8.68+00	2.89+01			4.10+01	3.76+01	7.97–01	7.31–01
5.00–02	1.07+01	8.42+00	1.44+01			2.51+01	2.28+01	4.89–01	4.44–01
6.00–02	9.84+00	8.18+00	8.16+00			1.80+01	1.63+01	3.50–01	3.18–01
8.00–02	8.71+00	7.76+00	3.31+00			1.20+01	1.11+01	2.34–01	2.15–01
1.00–01	8.00+00	7.39+00	1.61+00			9.61+00	9.00+00	1.87–01	1.75–01
1.50–01	6.93+00	6.65+00	4.53–01			7.39+00	7.11+00	1.44–01	1.38–01
2.00–01	6.25+00	6.10+00	1.85–01			6.44+00	6.28+00	1.25–01	1.22–01
3.00–01	5.38+00	5.30+00	5.41–02			5.43+00	5.36+00	1.06–01	1.04–01
4.00–01	4.79+00	4.75+00	2.35–02			4.81+00	4.78+00	9.36–02	9.28–02
5.00–01	4.36+00	4.34+00	1.27–02			4.37+00	4.35+00	8.50–02	8.46–02
6.00–01	4.03+00	4.01+00	7.95–03			4.03+00	4.02+00	7.84–02	7.82–02
8.00–01	3.54+00	3.53+00	4.01–03			3.54+00	3.53+00	6.88–02	6.86–02
1.00+00		3.17+00	2.49–03				3.17+00		6.17–02
1.50+00		2.58+00	1.17–03	1.03–02			2.59+00		5.03–02
2.00+00		2.20+00	7.36–04	4.05–02			2.24+00		4.36–02
3.00+00		1.73+00	4.07–04	1.15–01	6.04–04		1.85+00		3.59–02
4.00+00		1.44+00	2.76–04	1.86–01	2.48–03		1.63+00		3.17–02
5.00+00		1.25+00	2.11–04	2.49–01	4.87–03		1.50+00		2.92–02
6.00+00		1.10+00	1.67–04	3.04–01	7.49–03		1.41+00		2.75–02
8.00+00		9.01–01	1.19–04	3.98–01	1.28–02		1.31+00		2.55–02
1.00+01		7.67–01	9.32–05	4.73–01	1.75–02		1.26+00		2.45–02
1.50+01		5.68–01		6.16–01	2.73–02		1.21+00		2.36–02
2.00+01		4.56–01		7.20–01	3.50–02		1.21+00		2.35–02
3.00+01		3.32–01		8.66–01	4.66–02		1.24+00		2.42–02
4.00+01		2.64–01		9.67–01	5.52–02		1.29+00		2.50–02
5.00+01		2.20–01		1.04+00	6.17–02		1.32+00		2.57–02
6.00+01		1.90–01		1.10+00	6.68–02		1.36+00		2.64–02
8.00+01		1.50–01		1.19+00	7.47–02		1.41+00		2.74–02
1.00+02		1.24–01		1.25+00	8.06–02		1.45+00		2.83–02
1.50+02		8.84–02		1.35+00	9.09–02		1.53+00		2.98–02
2.00+02		6.93–02		1.41+00	9.78–02		1.58+00		3.07–02
3.00+02		4.91–02		1.49+00	1.06–01		1.64+00		3.19–02
4.00+02		3.85–02		1.53+00	1.12–01		1.68+00		3.27–02
5.00+02		3.18–02		1.56+00	1.16–01		1.71+00		3.32–02
6.00+02		2.73–02		1.58+00	1.19–01		1.72+00		3.35–02
8.00+02		2.13–02		1.60+00	1.23–01		1.75+00		3.40–02
1.00+03		1.75–02		1.62+00	1.26–01		1.77+00		3.44–02
1.50+03		1.22–02		1.65+00	1.31–01		1.79+00		3.48–02
2.00+03		9.47–03		1.66+00	1.34–01		1.81+00		3.51–02
3.00+03		6.58–03		1.68+00	1.37–01		1.82+00		3.54–02
4.00+03		5.08–03		1.69+00	1.39–01		1.83+00		3.56–02
5.00+03		4.16–03		1.69+00	1.40–01		1.84+00		3.57–02
6.00+03		3.52–03		1.70+00	1.41–01		1.84+00		3.58–02
8.00+03		2.71–03		1.70+00	1.42–01		1.85+00		3.59–02
1.00+04		2.22–03		1.70+00	1.43–01		1.85+00		3.59–02
1.50+04		1.53–03		1.71+00	1.44–01		1.85+00		3.60–02
2.00+04		1.18–03		1.71+00	1.44–01		1.86+00		3.61–02
3.00+04		8.12–04		1.71+00	1.45–01		1.86+00		3.61–02
4.00+04		6.24–04		1.71+00	1.45–01		1.86+00		3.61–02
5.00+04		5.08–04		1.71+00	1.45–01		1.86+00		3.62–02
6.00+04		4.29–04		1.71+00	1.45–01		1.86+00		3.62–02
8.00+04		3.29–04		1.71+00	1.46–01		1.86+00		3.62–02
1.00+05		2.68–04		1.72+00	1.46–01		1.86+00		3.62–02

(b/atom) x .019440 = cm²/g

Table 3.-12. SULFUR, Z=16

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00-02	4.52+01	1.02+01	2.67+03			2.72+03	2.68+03	5.10+01	5.03+01
1.50-02	3.03+01	1.01+01	8.00+02			8.30+02	8.10+02	1.56+01	1.52+01
2.00-02	2.28+01	9.89+00	3.32+02			3.55+02	3.42+02	6.66+00	6.42+00
3.00-02	1.62+01	9.56+00	9.40+01			1.10+02	1.04+02	2.07+00	1.94+00
4.00-02	1.33+01	9.26+00	3.82+01			5.15+01	4.75+01	9.68-01	8.91-01
5.00-02	1.17+01	8.98+00	1.91+01			3.08+01	2.81+01	5.79-01	5.27-01
6.00-02	1.07+01	8.73+00	1.08+01			2.15+01	1.95+01	4.04-01	3.67-01
8.00-02	9.41+00	8.28+00	4.40+00			1.38+01	1.27+01	2.59-01	2.38-01
1.00-01	8.61+00	7.88+00	2.16+00			1.08+01	1.00+01	2.02-01	1.89-01
1.50-01	7.43+00	7.10+00	6.10-01			8.04+00	7.71+00	1.51-01	1.45-01
2.00-01	6.69+00	6.50+00	2.51-01			6.94+00	6.75+00	1.30-01	1.27-01
3.00-01	5.73+00	5.66+00	7.35-02			5.81+00	5.73+00	1.09-01	1.08-01
4.00-01	5.11+00	5.07+00	3.19-02			5.14+00	5.10+00	9.66-02	9.58-02
5.00-01	4.66+00	4.63+00	1.73-02			4.67+00	4.65+00	8.78-02	8.72-02
6.00-01	4.30+00	4.28+00	1.08-02			4.31+00	4.29+00	8.10-02	8.06-02
8.00-01	3.77+00	3.76+00	5.48-03			3.77+00	3.77+00	7.09-02	7.08-02
1.00+00	3.39+00	3.38+00	3.39-03			3.40+00	3.39+00	6.38-02	6.36-02
1.50+00	2.74+00	2.75+00	1.59-03	1.18-02		2.76+00	2.76+00	5.18-02	5.19-02
2.00+00		2.34+00	1.00-03	4.62-02			2.39+00		4.49-02
3.00+00		1.84+00	5.53-04	1.31-01	6.44-04		1.98+00		3.71-02
4.00+00		1.54+00	3.74-04	2.12-01	2.64-03		1.75+00		3.29-02
5.00+00		1.33+00	2.86-04	2.83-01	5.19-03		1.62+00		3.04-02
6.00+00		1.17+00	2.27-04	3.46-01	7.99-03		1.53+00		2.87-02
8.00+00		9.61-01	1.62-04	4.52-01	1.37-02		1.43+00		2.68-02
1.00+01		8.18-01	1.26-04	5.38-01	1.87-02		1.38+00		2.58-02
1.50+01		6.06-01		7.00-01	2.91-02		1.34+00		2.51-02
2.00+01		4.86-01		8.18-01	3.73-02		1.34+00		2.52-02
3.00+01		3.54-01		9.83-01	4.98-02		1.39+00		2.61-02
4.00+01		2.81-01		1.10+00	5.88-02		1.44+00		2.70-02
5.00+01		2.35-01		1.18+00	6.57-02		1.48+00		2.78-02
6.00+01		2.02-01		1.25+00	7.11-02		1.52+00		2.86-02
8.00+01		1.60-01		1.35+00	7.95-02		1.59+00		2.98-02
1.00+02		1.33-01		1.42+00	8.58-02		1.64+00		3.07-02
1.50+02		9.43-02		1.53+00	9.67-02		1.72+00		3.24-02
2.00+02		7.39-02		1.60+00	1.04-01		1.78+00		3.34-02
3.00+02		5.24-02		1.68+00	1.13-01		1.85+00		3.48-02
4.00+02		4.10-02		1.73+00	1.19-01		1.89+00		3.56-02
5.00+02		3.40-02		1.77+00	1.23-01		1.92+00		3.61-02
6.00+02		2.91-02		1.79+00	1.26-01		1.95+00		3.65-02
8.00+02		2.27-02		1.82+00	1.31-01		1.97+00		3.70-02
1.00+03		1.87-02		1.84+00	1.34-01		1.99+00		3.74-02
1.50+03		1.30-02		1.87+00	1.39-01		2.02+00		3.80-02
2.00+03		1.01-02		1.89+00	1.42-01		2.04+00		3.83-02
3.00+03		7.02-03		1.90+00	1.45-01		2.06+00		3.86-02
4.00+03		5.42-03		1.91+00	1.47-01		2.06+00		3.88-02
5.00+03		4.43-03		1.92+00	1.49-01		2.07+00		3.89-02
6.00+03		3.76-03		1.92+00	1.49-01		2.08+00		3.90-02
8.00+03		2.90-03		1.93+00	1.50-01		2.08+00		3.91-02
1.00+04		2.37-03		1.93+00	1.51-01		2.08+00		3.91-02
1.50+04		1.63-03		1.94+00	1.52-01		2.09+00		3.92-02
2.00+04		1.26-03		1.94+00	1.53-01		2.09+00		3.93-02
3.00+04		8.66-04		1.94+00	1.53-01		2.09+00		3.93-02
4.00+04		6.65-04		1.94+00	1.54-01		2.10+00		3.94-02
5.00+04		5.42-04		1.94+00	1.54-01		2.10+00		3.94-02
6.00+04		4.58-04		1.94+00	1.54-01		2.10+00		3.94-02
8.00+04		3.51-04		1.94+00	1.54-01		2.10+00		3.94-02
1.00+05		2.86-04		1.94+00	1.54-01		2.10+00		3.94-02

(b/atom) x .018780 = cm²/g

Table 3.–13. ARGON, Z=18

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	5.66+01	1.15+01	4.22+03			4.28+03	4.23+03	6.45+01	6.38+01
1.50–02	3.84+01	1.13+01	1.28+03			1.32+03	1.29+03	1.99+01	1.95+01
2.00–02	2.87+01	1.11+01	5.37+02			5.66+02	5.48+02	8.53+00	8.27+00
3.00–02	1.97+01	1.08+01	1.54+02			1.74+02	1.65+02	2.62+00	2.48+00
4.00–02	1.59+01	1.04+01	6.34+01			7.93+01	7.38+01	1.20+00	1.11+00
5.00–02	1.38+01	1.01+01	3.17+01			4.55+01	4.18+01	6.87–01	6.30–01
6.00–02	1.25+01	9.82+00	1.80+01			3.05+01	2.78+01	4.60–01	4.20–01
8.00–02	1.09+01	9.31+00	7.40+00			1.83+01	1.67+01	2.75–01	2.52–01
1.00–01	9.87+00	8.87+00	3.65+00			1.35+01	1.25+01	2.04–01	1.89–01
1.50–01	8.44+00	7.98+00	1.05+00			9.49+00	9.03+00	1.43–01	1.36–01
2.00–01	7.58+00	7.32+00	4.34–01			8.01+00	7.75+00	1.21–01	1.17–01
3.00–01	6.48+00	6.36+00	1.28–01			6.61+00	6.49+00	9.96–02	9.79–02
4.00–01	5.77+00	5.70+00	5.57–02			5.82+00	5.76+00	8.78–02	8.68–02
5.00–01	5.24+00	5.21+00	3.01–02			5.27+00	5.24+00	7.95–02	7.90–02
6.00–01	4.84+00	4.82+00	1.89–02			4.86+00	4.84+00	7.33–02	7.29–02
8.00–01	4.24+00	4.23+00	9.60–03			4.25+00	4.24+00	6.41–02	6.40–02
1.00+00	3.82+00	3.80+00	5.95–03			3.82+00	3.81+00	5.76–02	5.75–02
1.50+00	3.10+00	3.09+00	2.77–03	1.51–02		3.11+00	3.11+00	4.70–02	4.69–02
2.00+00		2.64+00	1.75–03	5.88–02			2.70+00		4.07–02
3.00+00		2.08+00	9.6[illegible]–04	1.66–01	7.24–04		2.24+00		3.38–02
4.00+00		1.73+00	6.52–04	2.68–01	2.97–03		2.00+00		3.02–02
5.00+00		1.49+00	4.96–04	3.58–01	5.84–03		1.86+00		2.80–02
6.00+00		1.32+00	3.94–04	4.38–01	8.98–03		1.77+00		2.67–02
8.00+00		1.08+00	2.81–04	5.71–01	1.54–02		1.67+00		2.51–02
1.00+01		9.21–01	2.19–04	6.79–01	2.10–02		1.62+00		2.44–02
1.50+01		6.81–01		8.84–01	3.27–02		1.60+00		2.41–02
2.00+01		5.47–01		1.03+00	4.20–02		1.62+00		2.44–02
3.00+01		3.98–01		1.24+00	5.60–02		1.69+00		2.55–02
4.00+01		3.16–01		1.38+00	6.60–02		1.76+00		2.66–02
5.00+01		2.64–01		1.49+00	7.36–02		1.83+00		2.75–02
6.00+01		2.28–01		1.57+00	7.98–02		1.88+00		2.84–02
8.00+01		1.79–01		1.69+00	8.90–02		1.96+00		2.96–02
1.00+02		1.49–01		1.78+00	9.60–02		2.03+00		3.06–02
1.50+02		1.06–01		1.94+00	1.08–01		2.16+00		3.25–02
2.00+02		8.32–02		2.02+00	1.16–01		2.22+00		3.34–02
3.00+02		5.89–02		2.12+00	1.26–01		2.31+00		3.48–02
4.00+02		4.62–02		2.18+00	1.33–01		2.36+00		3.56–02
5.00+02		3.82–02		2.22+00	1.37–01		2.39+00		3.61–02
6.00+02		3.27–02		2.25+00	1.41–01		2.42+00		3.65–02
8.00+02		2.56–02		2.29+00	1.46–01		2.46+00		3.71–02
1.00+03		2.10–02		2.31+00	1.49–01		2.48+00		3.75–02
1.50+03		1.47–02		2.35+00	1.55–01		2.52+00		3.80–02
2.00+03		1.14–02		2.37+00	1.58–01		2.54+00		3.82–02
3.00+03		7.90–03		2.39+00	1.62–01		2.56+00		3.86–02
4.00+03		6.10–03		2.40+00	1.64–01		2.57+00		3.87–02
5.00+03		4.99–03		2.41+00	1.65–01		2.58+00		3.89–02
6.00+03		4.23–03		2.41+00	1.66–01		2.58+00		3.89–02
8.00+03		3.26–03		2.42+00	1.67–01		2.59+00		3.91–02
1.00+04		2.66–03		2.42+00	1.68–01		2.60+00		3.91–02
1.50+04		1.84–03		2.43+00	1.69–01		2.60+00		3.92–02
2.00+04		1.41–03		2.43+00	1.69–01		2.60+00		3.93–02
3.00+04		9.75–04		2.44+00	1.70–01		2.61+00		3.93–02
4.00+04		7.48–04		2.44+00	1.70–01		2.61+00		3.93–02
5.00+04		6.09–04		2.44+00	1.71–01		2.61+00		3.93–02
6.00+04		5.15–04		2.44+00	1.71–01		2.61+00		3.94–02
8.00+04		3.95–04		2.44+00	1.71–01		2.61+00		3.94–02
1.00+05		3.21–04		2.44+00	1.71–01		2.61+00		3.94–02

(b/atom) x .015080 = cm²/g

Table 3.-14. POTASSIUM, Z=19

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00-02	6.22+01	1.22+01	5.19+03			5.25+03	5.20+03	8.09+01	8.01+01
1.50-02	4.25+01	1.19+01	1.58+03			1.63+03	1.60+03	2.50+01	2.46+01
2.00-02	3.17+01	1.17+01	6.69+02			7.01+02	6.81+02	1.08+01	1.05+01
3.00-02	2.17+01	1.13+01	1.93+02			2.14+02	2.04+02	3.30+00	3.14+00
4.00-02	1.73+01	1.10+01	7.94+01			9.67+01	9.04+01	1.49+00	1.39+00
5.00-02	1.49+01	1.07+01	3.98+01			5.47+01	5.05+01	8.43-01	7.77-01
6.00-02	1.35+01	1.04+01	2.29+01			3.64+01	3.33+01	5.60-01	5.12-01
8.00-02	1.16+01	9.83+00	9.40+00			2.10+01	1.92+01	3.24-01	2.96-01
1.00-01	1.05+01	9.36+00	4.65+00			1.52+01	1.40+01	2.33-01	2.16-01
1.50-01	8.95+00	8.43+00	1.34+00			1.03+01	9.77+00	1.58-01	1.50-01
2.00-01	8.02+00	7.72+00	5.57-01			8.58+00	8.28+00	1.32-01	1.28-01
3.00-01	6.85+00	6.72+00	1.64-01			7.01+00	6.88+00	1.08-01	1.06-01
4.00-01	6.09+00	6.02+00	7.17-02			6.16+00	6.09+00	9.49-02	9.38-02
5.00-01	5.54+00	5.50+00	3.89-02			5.58+00	5.53+00	8.59-02	8.52-02
6.00-01	5.12+00	5.08+00	2.44-02			5.14+00	5.11+00	7.92-02	7.87-02
8.00-01	4.48+00	4.47+00	1.24-02			4.49+00	4.48+00	6.92-02	6.90-02
1.00+00	4.03+00	4.02+00	7.68-03			4.04+00	4.02+00	6.21-02	6.20-02
1.50+00	3.27+00	3.26+00	3.58-03	1.69-02		3.29+00	3.28+00	5.06-02	5.06-02
2.00+00		2.78+00	2.26-03	6.56-02			2.85+00		4.39-02
3.00+00		2.19+00	1.24-03	1.86-01	7.65-04		2.38+00		3.66-02
4.00+00		1.83+00	8.39-04	2.99-01	3.14-03		2.13+00		3.28-02
5.00+00		1.58+00	6.38-04	3.99-01	6.17-03		1.98+00		3.06-02
6.00+00		1.39+00	5.06-04	4.87-01	9.49-03		1.89+00		2.91-02
8.00+00		1.14+00	3.60-04	6.35-01	1.62-02		1.79+00		2.76-02
1.00+01		9.72-01	2.80-04	7.56-01	2.22-02		1.75+00		2.70-02
1.50+01		7.19-01		9.83-01	3.46-02		1.74+00		2.68-02
2.00+01		5.77-01		1.15+00	4.43-02		1.77+00		2.73-02
3.00+01		4.20-01		1.38+00	5.91-02		1.86+00		2.86-02
4.00+01		3.34-01		1.54+00	6.96-02		1.94+00		2.99-02
5.00+01		2.79-01		1.65+00	7.76-02		2.01+00		3.10-02
6.00+01		2.40-01		1.75+00	8.40-02		2.07+00		3.19-02
8.00+01		1.89-01		1.88+00	9.38-02		2.17+00		3.34-02
1.00+02		1.57-01		1.98+00	1.01-01		2.24+00		3.45-02
1.50+02		1.12-01		2.16+00	1.14-01		2.39+00		3.68-02
2.00+02		8.78-02		2.24+00	1.22-01		2.45+00		3.77-02
3.00+02		6.22-02		2.36+00	1.33-01		2.55+00		3.93-02
4.00+02		4.87-02		2.42+00	1.40-01		2.61+00		4.02-02
5.00+02		4.03-02		2.46+00	1.44-01		2.65+00		4.08-02
6.00+02		3.45-02		2.50+00	1.48-01		2.68+00		4.12-02
8.00+02		2.70-02		2.54+00	1.53-01		2.72+00		4.19-02
1.00+03		2.22-02		2.57+00	1.57-01		2.75+00		4.23-02
1.50+03		1.55-02		2.61+00	1.63-01		2.79+00		4.29-02
2.00+03		1.20-02		2.63+00	1.66-01		2.80+00		4.32-02
3.00+03		8.34-03		2.65+00	1.70-01		2.83+00		4.36-02
4.00+03		6.44-03		2.66+00	1.72-01		2.84+00		4.38-02
5.00+03		5.26-03		2.67+00	1.73-01		2.85+00		4.39-02
6.00+03		4.46-03		2.68+00	1.74-01		2.86+00		4.40-02
8.00+03		3.44-03		2.69+00	1.75-01		2.87+00		4.41-02
1.00+04		2.81-03		2.69+00	1.76-01		2.87+00		4.42-02
1.50+04		1.94-03		2.70+00	1.77-01		2.88+00		4.43-02
2.00+04		1.49-03		2.70+00	1.78-01		2.88+00		4.43-02
3.00+04		1.03-03		2.70+00	1.78-01		2.88+00		4.44-02
4.00+04		7.90-04		2.71+00	1.79-01		2.89+00		4.45-02
5.00+04		6.43-04		2.71+00	1.79-01		2.89+00		4.45-02
6.00+04		5.44-04		2.71+00	1.79-01		2.89+00		4.45-02
8.00+04		4.17-04		2.71+00	1.79-01		2.89+00		4.45-02
1.00+05		3.39-04		2.71+00	1.79-01		2.89+00		4.45-02

(b/atom) x .015400 = cm²/g

Table 3.-15. CALCIUM, Z=20

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00-02	6.78+01	1.28+01	6.35+03			6.42+03	6.36+03	9.65+01	9.56+01
1.50-02	4.68+01	1.26+01	1.96+03			2.00+03	1.97+03	3.01+01	2.96+01
2.00-02	3.49+01	1.24+01	8.27+02			8.62+02	8.39+02	1.30+01	1.26+01
3.00-02	2.36+01	1.19+01	2.42+02			2.66+02	2.54+02	3.99+00	3.82+00
4.00-02	1.87+01	1.16+01	9.98+01			1.19+02	1.11+02	1.78+00	1.67+00
5.00-02	1.61+01	1.12+01	5.03+01			6.64+01	6.15+01	9.98-01	9.25-01
6.00-02	1.44+01	1.09+01	2.87+01			4.31+01	3.96+01	6.48-01	5.95-01
8.00-02	1.24+01	1.03+01	1.19+01			2.43+01	2.22+01	3.65-01	3.34-01
1.00-01	1.12+01	9.85+00	5.89+00			1.71+01	1.57+01	2.56-01	2.37-01
1.50-01	9.47+00	8.87+00	1.70+00			1.12+01	1.06+01	1.68-01	1.59-01
2.00-01	8.47+00	8.13+00	7.09-01			9.17+00	8.84+00	1.38-01	1.33-01
3.00-01	7.22+00	7.07+00	2.10-01			7.43+00	7.28+00	1.12-01	1.09-01
4.00-01	6.42+00	6.33+00	9.19-02			6.51+00	6.43+00	9.79-02	9.66-02
5.00-01	5.84+00	5.79+00	4.98-02			5.89+00	5.84+00	8.85-02	8.78-02
6.00-01	5.39+00	5.35+00	3.13-02			5.42+00	5.38+00	8.14-02	8.09-02
8.00-01	4.72+00	4.70+00	1.59-02			4.74+00	4.72+00	7.12-02	7.09-02
1.00+00	4.24+00	4.23+00	9.87-03			4.25+00	4.24+00	6.39-02	6.37-02
1.50+00	3.44+00	3.44+00	4.58-03	1.88-02		3.46+00	3.46+00	5.20-02	5.20-02
2.00+00	2.93+00	2.93+00	2.90-03	7.30-02		3.01+00	3.01+00	4.53-02	4.52-02
3.00+00		2.31+00	1.59-03	2.06-01	8.05-04		2.51+00		3.78-02
4.00+00		1.92+00	1.07-03	3.31-01	3.30-03		2.26+00		3.40-02
5.00+00		1.66+00	8.16-04	4.42-01	6.49-03		2.11+00		3.17-02
6.00+00		1.47+00	6.46-04	5.40-01	9.98-03		2.02+00		3.03-02
8.00+00		1.20+00	4.60-04	7.03-01	1.71-02		1.92+00		2.89-02
1.00+01		1.02+00	3.59-04	8.36-01	2.33-02		1.88+00		2.83-02
1.50+01		7.57-01		1.09+00	3.64-02		1.88+00		2.83-02
2.00+01		6.08-01		1.27+00	4.67-02		1.92+00		2.89-02
3.00+01		4.42-01		1.52+00	6.22-02		2.03+00		3.05-02
4.00+01		3.52-01		1.70+00	7.32-02		2.12+00		3.19-02
5.00+01		2.93-01		1.83+00	8.16-02		2.20+00		3.31-02
6.00+01		2.53-01		1.93+00	8.83-02		2.27+00		3.42-02
8.00+01		1.99-01		2.08+00	9.85-02		2.38+00		3.58-02
1.00+02		1.66-01		2.19+00	1.06-01		2.46+00		3.70-02
1.50+02		1.18-01		2.39+00	1.20-01		2.62+00		3.94-02
2.00+02		9.24-02		2.48+00	1.28-01		2.70+00		4.05-02
3.00+02		6.55-02		2.60+00	1.39-01		2.81+00		4.22-02
4.00+02		5.13-02		2.67+00	1.46-01		2.87+00		4.32-02
5.00+02		4.25-02		2.72+00	1.51-01		2.92+00		4.38-02
6.00+02		3.64-02		2.76+00	1.55-01		2.95+00		4.43-02
8.00+02		2.84-02		2.81+00	1.60-01		2.99+00		4.50-02
1.00+03		2.34-02		2.84+00	1.64-01		3.03+00		4.55-02
1.50+03		1.63-02		2.88+00	1.70-01		3.07+00		4.61-02
2.00+03		1.26-02		2.90+00	1.74-01		3.09+00		4.64-02
3.00+03		8.78-03		2.93+00	1.78-01		3.12+00		4.68-02
4.00+03		6.78-03		2.94+00	1.80-01		3.13+00		4.70-02
5.00+03		5.54-03		2.95+00	1.81-01		3.14+00		4.72-02
6.00+03		4.70-03		2.96+00	1.82-01		3.14+00		4.73-02
8.00+03		3.62-03		2.97+00	1.83-01		3.15+00		4.74-02
1.00+04		2.96-03		2.97+00	1.84-01		3.16+00		4.75-02
1.50+04		2.04-03		2.98+00	1.85-01		3.17+00		4.76-02
2.00+04		1.57-03		2.98+00	1.86-01		3.17+00		4.77-02
3.00+04		1.08-03		2.99+00	1.86-01		3.17+00		4.77-02
4.00+04		8.31-04		2.99+00	1.87-01		3.18+00		4.77-02
5.00+04		6.77-04		2.99+00	1.87-01		3.18+00		4.78-02
6.00+04		5.72-04		2.99+00	1.87-01		3.18+00		4.78-02
8.00+04		4.39-04		2.99+00	1.87-01		3.18+00		4.78-02
1.00+05		3.57-04		2.99+00	1.87-01		3.18+00		4.78-02

(b/atom) x .015030 = cm²/g

Table 3.–16. IRON, Z=26

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	1.23+02	1.67+01	1.59+04			1.60+04	1.59+04	1.73+02	1.72+02
1.50–02	8.05+01	1.63+01	5.15+03			5.23+03	5.17+03	5.64+01	5.57+01
2.00–02	5.98+01	1.61+01	2.31+03			2.37+03	2.33+03	2.55+01	2.51+01
3.00–02	3.89+01	1.55+01	7.15+02			7.54+02	7.31+02	8.13+00	7.88+00
4.00–02	2.94+01	1.50+01	3.06+02			3.35+02	3.21+02	3.62+00	3.46+00
5.00–02	2.43+01	1.46+01	1.56+02			1.80+02	1.71+02	1.94+00	1.84+00
6.00–02	2.12+01	1.42+01	9.04+01			1.12+02	1.05+02	1.20+00	1.13+00
8.00–02	1.76+01	1.34+01	3.76+01			5.52+01	5.10+01	5.95–01	5.50–01
1.00–01	1.54+01	1.28+01	1.89+01			3.43+01	3.17+01	3.70–01	3.42–01
1.50–01	1.27+01	1.15+01	5.52+00			1.82+01	1.71+01	1.96–01	1.84–01
2.00–01	1.12+01	1.06+01	2.33+00			1.35+01	1.29+01	1.46–01	1.39–01
3.00–01	9.50+00	9.19+00	6.98–01			1.02+01	9.89+00	1.10–01	1.07–01
4.00–01	8.41+00	8.24+00	3.09–01			8.72+00	8.54+00	9.40–02	9.21–02
5.00–01	7.62+00	7.52+00	1.69–01			7.79+00	7.69+00	8.40–02	8.29–02
6.00–01	7.03+00	6.96+00	1.07–01			7.14+00	7.06+00	7.69–02	7.62–02
8.00–01	6.15+00	6.11+00	5.44–02			6.21+00	6.17+00	6.69–02	6.65–02
1.00+00	5.52+00	5.50+00	3.38–02			5.55+00	5.53+00	5.99–02	5.96–02
1.50+00	4.48+00	4.47+00	1.56–02	3.32–02		4.53+00	4.51+00	4.88–02	4.87–02
2.00+00		3.81+00	9.81–03	1.26–01			3.95+00		4.25–02
3.00+00		3.00+00	5.35–03	3.50–01	1.05–03		3.35+00		3.62–02
4.00+00		2.50+00	3.61–03	5.61–01	4.30–03		3.07+00		3.31–02
5.00+00		2.16+00	2.73–03	7.46–01	8.44–03		2.92+00		3.14–02
6.00+00		1.91+00	2.16–03	9.08–01	1.30–02		2.83+00		3.05–02
8.00+00		1.56+00	1.53–03	1.18+00	2.22–02		2.77+00		2.98–02
1.00+01		1.33+00	1.19–03	1.40+00	3.04–02		2.76+00		2.98–02
1.50+01		9.84–01	7.00–04	1.82+00	4.73–02		2.85+00		3.07–02
2.00+01		7.90–01	5.00–04	2.13+00	6.07–02		2.98+00		3.21–02
3.00+01		5.75–01		2.55+00	8.06–02		3.20+00		3.45–02
4.00+01		4.57–01		2.84+00	9.45–02		3.39+00		3.65–02
5.00+01		3.81–01		3.06+00	1.05–01		3.54+00		3.82–02
6.00+01		3.29–01		3.22+00	1.13–01		3.67+00		3.95–02
8.00+01		2.59–01		3.48+00	1.27–01		3.86+00		4.16–02
1.00+02		2.15–01		3.65+00	1.36–01		4.01+00		4.32–02
1.50+02		1.53–01		3.94+00	1.53–01		4.25+00		4.58–02
2.00+02		1.20–01		4.12+00	1.64–01		4.40+00		4.75–02
3.00+02		8.51–02		4.32+00	1.78–01		4.58+00		4.94–02
4.00+02		6.67–02		4.44+00	1.86–01		4.69+00		5.06–02
5.00+02		5.52–02		4.52+00	1.92–01		4.77+00		5.14–02
6.00+02		4.73–02		4.57+00	1.97–01		4.82+00		5.19–02
8.00+02		3.69–02		4.65+00	2.04–01		4.89+00		5.27–02
1.00+03		3.04–02		4.69+00	2.09–01		4.93+00		5.32–02
1.50+03		2.12–02		4.77+00	2.16–01		5.00+00		5.39–02
2.00+03		1.64–02		4.80+00	2.20–01		5.04+00		5.43–02
3.00+03		1.14–02		4.84+00	2.24–01		5.08+00		5.48–02
4.00+03		8.81–03		4.86+00	2.26–01		5.10+00		5.50–02
5.00+03		7.20–03		4.88+00	2.28–01		5.11+00		5.51–02
6.00+03		6.11–03		4.89+00	2.29–01		5.13+00		5.52–02
8.00+03		4.71–03		4.90+00	2.31–01		5.14+00		5.54–02
1.00+04		3.84–03		4.91+00	2.31–01		5.14+00		5.55–02
1.50+04		2.66–03		4.92+00	2.33–01		5.16+00		5.56–02
2.00+04		2.04–03		4.93+00	2.33–01		5.16+00		5.56–02
3.00+04		1.41–03		4.93+00	2.34–01		5.17+00		5.57–02
4.00+04		1.08–03		4.93+00	2.35–01		5.17+00		5.57–02
5.00+04		8.80–04		4.94+00	2.35–01		5.17+00		5.58–02
6.00+04		7.44–04		4.94+00	2.35–01		5.17+00		5.58–02
8.00+04		5.70–04		4.94+00	2.35–01		5.17+00		5.58–02
1.00+05		4.64–04		4.94+00	2.36–01		5.17+00		5.58–02

(b/atom) x .010780 = cm²/g

Table 3.–17. COPPER, Z=29

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm^2/g*	*cm^2/g*
1.00–02	1.66+02	1.86+01	2.35+04			2.37+04	2.35+04	2.24+02	2.23+02
1.50–02	1.06+02	1.82+01	7.72+03			7.83+03	7.74+03	7.42+01	7.33+01
2.00–02	7.70+01	1.79+01	3.46+03			3.54+03	3.48+03	3.35+01	3.30+01
3.00–02	4.92+01	1.73+01	1.11+03			1.15+03	1.12+03	1.09+01	1.06+01
4.00–02	3.64+01	1.68+01	4.80+02			5.16+02	4.97+02	4.89+00	4.71+00
5.00–02	2.96+01	1.63+01	2.47+02			2.77+02	2.63+02	2.62+00	2.50+00
6.00–02	2.55+01	1.58+01	1.45+02			1.71+02	1.61+02	1.62+00	1.52+00
8.00–02	2.07+01	1.50+01	6.08+01			8.14+01	7.58+01	7.72–01	7.18–01
1.00–01	1.79+01	1.43+01	3.08+01			4.87+01	4.51+01	4.61–01	4.27–01
1.50–01	1.45+01	1.29+01	9.04+00			2.36+01	2.19+01	2.23–01	2.08–01
2.00–01	1.27+01	1.18+01	3.80+00			1.65+01	1.56+01	1.57–01	1.48–01
3.00–01	1.07+01	1.02+01	1.15+00			1.18+01	1.14+01	1.12–01	1.08–01
4.00–01	9.42+00	9.19+00	5.12–01			9.93+00	9.70+00	9.41–02	9.19–02
5.00–01	8.54+00	8.39+00	2.81–01			8.82+00	8.67+00	8.36–02	8.22–02
6.00–01	7.86+00	7.76+00	1.77–01			8.04+00	7.94+00	7.62–02	7.52–02
8.00–01	6.87+00	6.82+00	9.11–02			6.96+00	6.91+00	6.60–02	6.55–02
1.00+00	6.16+00	6.13+00	5.65–02			6.22+00	6.19+00	5.89–02	5.86–02
1.50+00	4.99+00	4.98+00	2.61–02	4.23–02		5.06+00	5.05+00	4.80–02	4.79–02
2.00+00	4.25+00	4.25+00	1.63–02	1.58–01		4.43+00	4.43+00	4.20–02	4.19–02
3.00+00	3.35+00	3.34+00	8.88–03	4.38–01	1.17–03	3.79+00	3.79+00	3.60–02	3.59–02
4.00+00		2.79+00	5.96–03	6.98–01	4.79–03		3.50+00		3.32–02
5.00+00		2.41+00	4.50–03	9.28–01	9.41–03		3.35+00		3.18–02
6.00+00		2.13+00	3.56–03	1.13+00	1.45–02		3.28+00		3.10–02
8.00+00		1.74+00	2.52–03	1.46+00	2.48–02		3.23+00		3.06–02
1.00+01		1.48+00	1.95–03	1.74+00	3.39–02		3.25+00		3.08–02
1.50+01		1.10+00	1.20–03	2.25+00	5.27–02		3.41+00		3.23–02
2.00+01		8.81–01	9.00–04	2.63+00	6.77–02		3.58+00		3.39–02
3.00+01		6.41–01	6.00–04	3.15+00	8.97–02		3.89+00		3.68–02
4.00+01		5.10–01	4.00–04	3.51+00	1.05–01		4.13+00		3.91–02
5.00+01		4.25–01		3.78+00	1.17–01		4.32+00		4.10–02
6.00+01		3.67–01		3.99+00	1.26–01		4.48+00		4.25–02
8.00+01		2.89–01		4.30+00	1.41–01		4.73+00		4.48–02
1.00+02		2.40–01		4.52+00	1.51–01		4.91+00		4.65–02
1.50+02		1.71–01		4.87+00	1.70–01		5.21+00		4.94–02
2.00+02		1.34–01		5.08+00	1.82–01		5.39+00		5.11–02
3.00+02		9.50–02		5.32+00	1.97–01		5.61+00		5.32–02
4.00+02		7.44–02		5.46+00	2.06–01		5.74+00		5.44–02
5.00+02		6.16–02		5.55+00	2.13–01		5.83+00		5.52–02
6.00+02		5.27–02		5.62+00	2.18–01		5.89+00		5.58–02
8.00+02		4.12–02		5.71+00	2.25–01		5.97+00		5.66–02
1.00+03		3.39–02		5.77+00	2.30–01		6.03+00		5.72–02
1.50+03		2.37–02		5.85+00	2.38–01		6.11+00		5.79–02
2.00+03		1.83–02		5.89+00	2.42–01		6.15+00		5.83–02
3.00+03		1.27–02		5.94+00	2.47–01		6.20+00		5.88–02
4.00+03		9.83–03		5.97+00	2.49–01		6.23+00		5.90–02
5.00+03		8.03–03		5.98+00	2.51–01		6.24+00		5.91–02
6.00+03		6.81–03		5.99+00	2.52–01		6.25+00		5.93–02
8.00+03		5.25–03		6.01+00	2.54–01		6.26+00		5.94–02
1.00+04		4.29–03		6.01+00	2.55–01		6.27+00		5.95–02
1.50+04		2.96–03		6.03+00	2.56–01		6.29+00		5.96–02
2.00+04		2.28–03		6.03+00	2.57–01		6.29+00		5.96–02
3.00+04		1.57–03		6.05+00	2.58–01		6.31+00		5.98–02
4.00+04		1.21–03		6.05+00	2.58–01		6.31+00		5.98–02
5.00+04		9.82–04		6.05+00	2.58–01		6.31+00		5.98–02
6.00+04		8.30–04		6.05+00	2.58–01		6.31+00		5.98–02
8.00+04		6.36–04		6.05+00	2.59–01		6.31+00		5.98–02
1.00+05		5.18–04		6.05+00	2.59–01		6.31+00		5.98–02

(b/atom) x .009478 = cm^2/g

Table 3.−18. MOLYBDENUM, Z=42

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00−02	3.77+02	2.69+01	1.34+04			1.37+04	1.34+04	8.62+01	8.40+01
1.50−02	2.46+02	2.64+01	4.24+03			4.49+03	4.27+03	2.82+01	2.68+01
2.00−02	1.74+02	2.59+01	1.84+03			2.01+03	1.87+03	1.26+01	1.17+01
K 2.00−02	1.74+02	2.59+01	1.28+04			1.30+04	1.29+04	8.17+01	8.08+01
3.00−02	1.07+02	2.51+01	4.48+03			4.59+03	4.51+03	2.88+01	2.83+01
4.00−02	7.64+01	2.43+01	2.04+03			2.12+03	2.07+03	1.33+01	1.30+01
5.00−02	5.94+01	2.36+01	1.09+03			1.15+03	1.11+03	7.20+00	6.97+00
6.00−02	4.90+01	2.29+01	6.54+02			7.03+02	6.77+02	4.41+00	4.25+00
8.00−02	3.71+01	2.17+01	2.85+02			3.22+02	3.06+02	2.02+00	1.92+00
1.00−01	3.06+01	2.07+01	1.47+02			1.78+02	1.68+02	1.11+00	1.05+00
1.50−01	2.32+01	1.86+01	4.50+01			6.82+01	6.36+01	4.28−01	3.99−01
2.00−01	1.97+01	1.71+01	1.93+01			3.90+01	3.64+01	2.45−01	2.28−01
3.00−01	1.60+01	1.48+01	6.02+00			2.21+01	2.09+01	1.39−01	1.31−01
4.00−01	1.39+01	1.33+01	2.74+00			1.67+01	1.60+01	1.05−01	1.01−01
5.00−01	1.25+01	1.22+01	1.53+00			1.41+01	1.37+01	8.83−02	8.59−02
6.00−01	1.16+01	1.12+01	9.80−01			1.25+01	1.22+01	7.88−02	7.67−02
8.00−01	1.00+01	9.88+00	5.04−01			1.05+01	1.04+01	6.61−02	6.52−02
1.00+00	8.97+00	8.88+00	3.13−01			9.29+00	9.19+00	5.83−02	5.77−02
1.50+00	7.25+00	7.21+00	1.43−01	9.99−02		7.49+00	7.46+00	4.70−02	4.68−02
2.00+00	6.17+00	6.16+00	8.84−02	3.54−01		6.62+00	6.60+00	4.15−02	4.14−02
3.00+00	4.84+00	4.84+00	4.77−02	9.40−01	1.69−03	5.83+00	5.83+00	3.66−02	3.66−02
4.00+00	4.05+00	4.04+00	3.18−02	1.47+00	6.94−03	5.56+00	5.55+00	3.49−02	3.48−02
5.00+00	3.50+00	3.49+00	2.39−02	1.94+00	1.36−02	5.47+00	5.47+00	3.44−02	3.43−02
6.00+00		3.08+00	1.88−02	2.34+00	2.10−02		5.46+00		3.43−02
8.00+00		2.52+00	1.31−02	3.01+00	3.59−02		5.58+00		3.50−02
1.00+01		2.15+00	1.02−02	3.55+00	4.90−02		5.76+00		3.62−02
1.50+01		1.59+00	6.39−03	4.59+00	7.64−02		6.27+00		3.93−02
2.00+01		1.28+00	4.65−03	5.36+00	9.78−02		6.74+00		4.23−02
3.00+01		9.29−01	3.01−03	6.43+00	1.28−01		7.49+00		4.70−02
4.00+01		7.38−01	2.22−03	7.15+00	1.50−01		8.04+00		5.05−02
5.00+01		6.16−01	1.76−03	7.69+00	1.66−01		8.47+00		5.32−02
6.00+01		5.31−01	1.46−03	8.10+00	1.79−01		8.82+00		5.53−02
8.00+01		4.19−01	1.08−03	8.72+00	1.99−01		9.34+00		5.86−02
1.00+02		3.48−01	8.65−04	9.14+00	2.15−01		9.71+00		6.09−02
1.50+02		2.48−01		9.83+00	2.40−01		1.03+01		6.48−02
2.00+02		1.94−01		1.02+01	2.56−01		1.07+01		6.72−02
3.00+02		1.38−01		1.07+01	2.76−01		1.12+01		7.00−02
4.00+02		1.08−01		1.10+01	2.89−01		1.14+01		7.16−02
5.00+02		8.92−02		1.12+01	2.97−01		1.16+01		7.27−02
6.00+02		7.63−02		1.13+01	3.04−01		1.17+01		7.35−02
8.00+02		5.96−02		1.15+01	3.14−01		1.19+01		7.45−02
1.00+03		4.91−02		1.16+01	3.20−01		1.20+01		7.53−02
1.50+03		3.43−02		1.18+01	3.30−01		1.21+01		7.62−02
2.00+03		2.65−02		1.19+01	3.35−01		1.22+01		7.67−02
3.00+03		1.84−02		1.20+01	3.41−01		1.23+01		7.73−02
4.00+03		1.42−02		1.20+01	3.44−01		1.24+01		7.77−02
5.00+03		1.16−02		1.20+01	3.46−01		1.24+01		7.79−02
6.00+03		9.87−03		1.21+01	3.48−01		1.24+01		7.80−02
8.00+03		7.60−03		1.21+01	3.50−01		1.24+01		7.81−02
1.00+04		6.21−03		1.21+01	3.51−01		1.25+01		7.83−02
1.50+04		4.29−03		1.22+01	3.53−01		1.25+01		7.85−02
2.00+04		3.30−03		1.22+01	3.54−01		1.25+01		7.85−02
3.00+04		2.27−03		1.22+01	3.55−01		1.25+01		7.86−02
4.00+04		1.75−03		1.22+01	3.55−01		1.25+01		7.86−02
5.00+04		1.42−03		1.22+01	3.55−01		1.25+01		7.86−02
6.00+04		1.20−03		1.22+01	3.56−01		1.25+01		7.87−02
8.00+04		9.22−04		1.22+01	3.56−01		1.25+01		7.88−02
1.00+05		7.50−04		1.22+01	3.56−01		1.25+01		7.88−02

(b/atom) x .006277 = cm²/g

Table 3.–19. TIN, Z=50

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00–02	5.38+02	3.20+01	2.73+04			2.79+04	2.74+04	1.41+02	1.39+02
1.50–02	3.60+02	3.14+01	8.91+03			9.27+03	8.94+03	4.70+01	4.53+01
2.00–02	2.59+02	3.09+01	3.95+03			4.21+03	3.98+03	2.13+01	2.02+01
2.92–02	1.61+02	2.99+01	1.33+03			1.49+03	1.36+03	7.54+00	6.88+00
K 2.92–02	1.61+02	2.99+01	8.57+03			8.73+03	8.60+03	4.43+01	4.37+01
3.00–02	1.56+02	2.99+01	7.98+03			8.14+03	8.01+03	4.13+01	4.07+01
4.00–02	1.10+02	2.89+01	3.70+03			3.81+03	3.73+03	1.94+01	1.89+01
5.00–02	8.44+01	2.81+01	2.02+03			2.10+03	2.04+03	1.07+01	1.04+01
6.00–02	6.85+01	2.73+01	1.22+03			1.29+03	1.25+03	6.53+00	6.32+00
8.00–02	5.02+01	2.59+01	5.45+02			5.95+02	5.71+02	3.02+00	2.90+00
1.00–01	4.05+01	2.46+01	2.90+02			3.31+02	3.15+02	1.68+00	1.60+00
1.50–01	2.96+01	2.22+01	9.15+01			1.21+02	1.14+02	6.14–01	5.77–01
2.00–01	2.45+01	2.03+01	4.02+01			6.47+01	6.06+01	3.28–01	3.07–01
3.00–01	1.96+01	1.77+01	1.28+01			3.24+01	3.05+01	1.64–01	1.55–01
4.00–01	1.69+01	1.58+01	5.93+00			2.28+01	2.18+01	1.16–01	1.10–01
5.00–01	1.51+01	1.45+01	3.50+00			1.86+01	1.80+01	9.46–02	9.11–02
6.00–01	1.39+01	1.34+01	2.20+00			1.61+01	1.56+01	8.16–02	7.91–02
8.00–01	1.20+01	1.18+01	1.15+00			1.32+01	1.29+01	6.69–02	6.55–02
1.00+00	1.07+01	1.06+01	6.90–01			1.14+01	1.13+01	5.78–02	5.71–02
1.50+00	8.65+00	8.59+00	3.13–01	1.53–01		9.12+00	9.06+00	4.63–02	4.59–02
2.00+00	7.36+00	7.33+00	1.93–01	5.23–01		8.08+00	8.04+00	4.10–02	4.08–02
3.00+00	5.77+00	5.77+00	1.05–01	1.35+00	2.01–03	7.24+00	7.23+00	3.67–02	3.67–02
4.00+00	4.82+00	4.81+00	6.93–02	2.10+00	8.26–03	7.00+00	6.98+00	3.55–02	3.54–02
5.00+00	4.16+00	4.15+00	5.18–02	2.74+00	1.62–02	6.97+00	6.96+00	3.54–02	3.53–02
6.00+00	3.68+00	3.67+00	4.05–02	3.29+00	2.50–02	7.03+00	7.03+00	3.57–02	3.57–02
8.00+00		3.00+00	2.83–02	4.21+00	4.27–02		7.28+00		3.69–02
1.00+01		2.56+00	2.18–02	4.95+00	5.84–02		7.58+00		3.85–02
1.50+01		1.89+00	1.37–02	6.38+00	9.09–02		8.37+00		4.25–02
2.00+01		1.52+00	9.94–03	7.44+00	1.16–01		9.08+00		4.61–02
3.00+01		1.11+00	6.41–03	8.92+00	1.52–01		1.02+01		5.17–02
4.00+01		8.79–01	4.73–03	9.92+00	1.77–01		1.10+01		5.57–02
5.00+01		7.34–01	3.75–03	1.07+01	1.96–01		1.16+01		5.88–02
6.00+01		6.32–01	3.10–03	1.12+01	2.11–01		1.21+01		6.13–02
8.00+01		4.98–01	2.31–03	1.21+01	2.35–01		1.28+01		6.51–02
1.00+02		4.14–01	1.84–03	1.27+01	2.52–01		1.33+01		6.77–02
1.50+02		2.95–01		1.36+01	2.81–01		1.42+01		7.21–02
2.00+02		2.31–01		1.42+01	3.00–01		1.47+01		7.48–02
3.00+02		1.64–01		1.49+01	3.23–01		1.54+01		7.80–02
4.00+02		1.28–01		1.53+01	3.38–01		1.57+01		7.98–02
5.00+02		1.06–01		1.55+01	3.48–01		1.60+01		8.10–02
6.00+02		9.09–02		1.57+01	3.56–01		1.61+01		8.19–02
8.00+02		7.10–02		1.59+01	3.67–01		1.64+01		8.31–02
1.00+03		5.84–02		1.61+01	3.74–01		1.65+01		8.38–02
1.50+03		4.08–02		1.63+01	3.84–01		1.67+01		8.49–02
2.00+03		3.16–02		1.64+01	3.90–01		1.69+01		8.56–02
3.00+03		2.19–02		1.66+01	3.97–01		1.70+01		8.62–02
4.00+03		1.69–02		1.66+01	4.00–01		1.70+01		8.65–02
5.00+03		1.38–02		1.67+01	4.03–01		1.71+01		8.67–02
6.00+03		1.17–02		1.67+01	4.04–01		1.71+01		8.68–02
8.00+03		9.05–03		1.67+01	4.06–01		1.72+01		8.70–02
1.00+04		7.39–03		1.68+01	4.08–01		1.72+01		8.71–02
1.50+04		5.11–03		1.68+01	4.10–01		1.72+01		8.73–02
2.00+04		3.93–03		1.68+01	4.11–01		1.72+01		8.74–02
3.00+04		2.71–03		1.68+01	4.12–01		1.73+01		8.75–02
4.00+04		2.08–03		1.68+01	4.12–01		1.73+01		8.76–02
5.00+04		1.69–03		1.69+01	4.13–01		1.73+01		8.77–02
6.00+04		1.43–03		1.69+01	4.13–01		1.73+01		8.77–02
8.00+04		1.10–03		1.69+01	4.13–01		1.73+01		8.77–02
1.00+05		8.93–03		1.69+01	4.14–01		1.73+01		8.77–02

(b/atom) x .005074 = cm²/g

Table 3.-20. IODINE, Z=53

Photon energy	Scattering		Photo-electric	Pair production		Total		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent	With coherent	Without coherent
MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
1.00-02	6.07+02	3.39+01	3.33+04			3.39+04	3.33+04	1.61+02	1.58+02
1.50-02	4.05+02	3.33+01	1.12+04			1.16+04	1.13+04	5.52+01	5.34+01
2.00-02	2.94+02	3.28+01	5.18+03			5.47+03	5.21+03	2.60+01	2.47+01
3.00-02	1.77+02	3.17+01	1.65+03			1.83+03	1.68+03	8.67+00	7.98+00
3.32-02	1.56+02	3.13+01	1.24+03			1.40+03	1.27+03	6.62+00	6.03+00
K 3.32-02	1.56+02	3.13+01	7.52+03			7.68+03	7.55+03	3.64+01	3.58+01
4.00-02	1.23+02	3.07+01	4.66+03			4.79+03	4.69+03	2.27+01	2.23+01
5.00-02	9.48+01	2.98+01	2.57+03			2.66+03	2.60+03	1.26+01	1.23+01
6.00-02	7.69+01	2.89+01	1.56+03			1.64+03	1.59+03	7.78+00	7.55+00
8.00-02	5.58+01	2.74+01	7.14+02			7.69+02	7.41+02	3.65+00	3.52+00
1.00-01	4.46+01	2.61+01	3.77+02			4.22+02	4.03+02	2.00+00	1.91+00
1.50-01	3.21+01	2.35+01	1.18+02			1.50+02	1.42+02	7.14-01	6.74-01
2.00-01	2.64+01	2.15+01	5.21+01			7.85+01	7.36+01	3.72-01	3.49-01
3.00-01	2.09+01	1.87+01	1.66+01			3.76+01	3.53+01	1.78-01	1.68-01
4.00-01	1.80+01	1.68+01	7.71+00			2.57+01	2.45+01	1.22-01	1.16-01
5.00-01	1.62+01	1.53+01	4.40+00			2.06+01	1.97+01	9.76-02	9.36-02
6.00-01	1.48+01	1.42+01	2.83+00			1.76+01	1.70+01	8.35-02	8.07-02
8.00-01	1.28+01	1.25+01	1.46+00			1.42+01	1.39+01	6.76-02	6.61-02
1.00+00	1.13+01	1.12+01	9.11-01			1.23+01	1.21+01	5.81-02	5.75-02
1.50+00	9.18+00	9.10+00	4.13-01	1.78-01		9.77+00	9.70+00	4.64-02	4.60-02
2.00+00	7.80+00	7.77+00	2.54-01	5.98-01		8.65+00	8.62+00	4.11-02	4.09-02
3.00+00	6.12+00	6.11+00	1.36-01	1.53+00	2.13-03	7.79+00	7.78+00	3.70-02	3.69-02
4.00+00	5.12+00	5.10+00	8.97-02	2.36+00	8.76-03	7.57+00	7.56+00	3.59-02	3.59-02
5.00+00	4.41+00	4.40+00	6.70-02	3.08+00	1.72-02	7.57+00	7.56+00	3.59-02	3.59-02
6.00+00	3.90+00	3.89+00	5.25-02	3.69+00	2.65-02	7.66+00	7.66+00	3.64-02	3.63-02
8.00+00		3.18+00	3.66-02	4.70+00	4.53-02		7.96+00		3.78-02
1.00+01		2.71+00	2.82-02	5.52+00	6.19-02		8.32+00		3.95-02
1.50+01		2.01+00	1.76-02	7.10+00	9.64-02		9.22+00		4.38-02
2.00+01		1.61+00	1.28-02	8.29+00	1.23-01		1.00+01		4.76-02
3.00+01		1.17+00	8.25-03	9.95+00	1.60-01		1.13+01		5.36-02
4.00+01		9.32-01	6.09-03	1.11+01	1.87-01		1.22+01		5.78-02
5.00+01		7.78-01	4.83-03	1.19+01	2.07-01		1.29+01		6.11-02
6.00+01		6.70-01	3.99-03	1.25+01	2.23-01		1.34+01		6.37-02
8.00+01		5.28-01	2.97-03	1.35+01	2.48-01		1.42+01		6.76-02
1.00+02		4.39-01	2.37-03	1.41+01	2.66-01		1.48+01		7.04-02
1.50+02		3.12-01		1.52+01	2.97-01		1.58+01		7.50-02
2.00+02		2.45-01		1.58+01	3.16-01		1.64+01		7.78-02
3.00+02		1.74-01		1.66+01	3.40-01		1.71+01		8.11-02
4.00+02		1.36-01		1.70+01	3.56-01		1.75+01		8.30-02
5.00+02		1.12-01		1.73+01	3.67-01		1.77+01		8.42-02
6.00+02		9.63-02		1.75+01	3.75-01		1.79+01		8.51-02
8.00+02		7.52-02		1.78+01	3.86-01		1.82+01		8.64-02
1.00+03		6.19-02		1.79+01	3.94-01		1.84+01		8.71-02
1.50+03		4.32-02		1.82+01	4.05-01		1.86+01		8.84-02
2.00+03		3.35-02		1.83+01	4.11-01		1.88+01		8.90-02
3.00+03		2.33-02		1.84+01	4.17-01		1.89+01		8.96-02
4.00+03		1.80-02		1.85+01	4.21-01		1.90+01		9.00-02
5.00+03		1.47-02		1.86+01	4.23-01		1.90+01		9.02-02
6.00+03		1.24-02		1.86+01	4.25-01		1.90+01		9.04-02
8.00+03		9.59-03		1.86+01	4.27-01		1.91+01		9.05-02
1.00+04		7.83-03		1.87+01	4.29-01		1.91+01		9.06-02
1.50+04		5.41-03		1.87+01	4.31-01		1.91+01		9.08-02
2.00+04		4.16-03		1.87+01	4.32-01		1.92+01		9.10-02
3.00+04		2.87-03		1.88+01	4.33-01		1.92+01		9.11-02
4.00+04		2.20-03		1.88+01	4.33-01		1.92+01		9.11-02
5.00+04		1.79-03		1.88+01	4.34-01		1.92+01		9.11-02
6.00+04		1.52-03		1.88+01	4.34-01		1.92+01		9.12-02
8.00+04		1.16-03		1.88+01	4.34-01		1.92+01		9.12-02
1.00+05		9.46-04		1.88+01	4.35-01		1.92+01		9.12-02

(b/atom) x .004746 = cm²/g

Table 3.–21. TUNGSTEN, Z = 74

	Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
	MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
	1.00–02	1.38+03	4.74+01	2.78+04			2.92+04	2.78+04	9.55+01	9.12+01
	1.02–02	1.35+03	4.74+01	2.63+04			2.77+04	2.64+04	9.07+01	8.64+01
L_3	1.02–02	1.35+03	4.74+01	7.04+04			7.18+04	7.05+04	2.35+02	2.31+02
	1.15–02	1.20+03	4.71+01	5.06+04			5.17+04	5.06+04	1.70+02	1.66+02
L_2	1.15–02	1.20+03	4.71+01	7.05+04			7.17+04	7.05+04	2.35+02	2.31+02
	1.21–02	1.14+03	4.70+01	6.17+04			6.29+04	6.18+04	2.06+02	2.02+02
L_1	1.21–02	1.14+03	4.70+01	7.45+04			7.56+04	7.45+04	2.48+02	2.44+02
	1.50–02	8.99+02	4.65+01	4.25+04			4.34+04	4.25+04	1.42+02	1.39+02
	2.00–02	6.39+02	4.57+01	1.98+04			2.05+04	1.99+04	6.70+01	6.51+01
	3.00–02	3.88+02	4.42+01	6.62+03			7.01+03	6.67+03	2.30+01	2.18+01
	4.00–02	2.65+02	4.28+01	3.00+03			3.26+03	3.04+03	1.07+01	9.97+00
	5.00–02	1.96+02	4.16+01	1.61+03			1.80+03	1.65+03	5.91+00	5.40+00
	6.00–02	1.54+02	4.04+01	9.61+02			1.12+03	1.00+03	3.65+00	3.28+00
	6.95–02	1.28+02	3.93+01	6.32+02			7.60+02	6.71+02	2.49+00	2.20+00
K	6.95–02	1.28+02	3.93+01	3.33+03			3.46+03	3.37+03	1.13+01	1.10+01
	8.00–02	1.07+02	3.83+01	2.30+03			2.41+03	2.34+03	7.89+00	7.66+00
	1.00–01	8.13+01	3.65+01	1.27+03			1.35+03	1.31+03	4.43+00	4.29+00
	1.50–01	5.38+01	3.28+01	4.26+02			4.80+02	4.59+02	1.57+00	1.50+00
	2.00–01	4.20+01	3.01+01	1.95+02			2.37+02	2.25+02	7.77–01	7.38–01
	3.00–01	3.15+01	2.62+01	6.60+01			9.75+01	9.22+01	3.20–01	3.02–01
	4.00–01	2.65+01	2.34+01	3.14+01			5.79+01	5.48+01	1.90–01	1.80–01
	5.00–01	2.34+01	2.14+01	1.81+01			4.15+01	3.95+01	1.36–01	1.29–01
	6.00–01	2.12+01	1.98+01	1.17+01			3.29+01	3.15+01	1.08–01	1.03–01
	8.00–01	1.82+01	1.74+01	6.20+00			2.44+01	2.36+01	7.99–02	7.73–02
	1.00+00	1.61+01	1.56+01	3.88+00			2.00+01	1.95+01	6.54–02	6.39–02
	1.50+00	1.30+01	1.27+01	1.77+00	4.28–01		1.52+01	1.49+01	4.97–02	4.88–02
	2.00+00	1.09+01	1.08+01	1.06+00	1.32+00		1.33+01	1.32+01	4.37–02	4.34–02
	3.00+00	8.57+00	8.53+00	5.58–01	3.15+00	2.98–03	1.23+01	1.22+01	4.02–02	4.01–02
	4.00+00	7.16+00	7.12+00	3.62–01	4.67+00	1.22–02	1.22+01	1.22+01	4.00–02	3.98–02
	5.00+00	6.17+00	6.15+00	2.68–01	5.96+00	2.40–02	1.24+01	1.24+01	4.07–02	4.06–02
	6.00+00	5.45+00	5.43+00	2.08–01	7.02+00	3.69–02	1.27+01	1.27+01	4.16–02	4.16–02
	8.00+00	4.45+00	4.44+00	1.44–01	8.76+00	6.32–02	1.34+01	1.34+01	4.39–02	4.39–02
	1.00+01	3.80+00	3.78+00	1.10–01	1.02+01	8.64–02	1.42+01	1.41+01	4.64–02	4.63–02
	1.50+01		2.80+00	6.88–02	1.30+01	1.34–01		1.60+01		5.24–02
	2.00+01		2.25+00	4.97–02	1.51+01	1.69–01		1.76+01		5.77–02
	3.00+01		1.64+00	3.20–02	1.82+01	2.19–01		2.01+01		6.59–02
	4.00+01		1.30+00	2.36–02	2.03+01	2.55–01		2.19+01		7.16–02
	5.00+01		1.09+00	1.87–02	2.18+01	2.83–01		2.32+01		7.60–02
	6.00+01		9.35–01	1.55–02	2.30+01	3.05–01		2.42+01		7.94–02
	8.00+01		7.38–01	1.15–02	2.47+01	3.38–01		2.58+01		8.45–02
	1.00+02		6.13–01	9.20–03	2.59+01	3.62–01		2.69+01		8.81–02
	1.50+02		4.36–01		2.78+01	4.02–01		2.87+01		9.39–02
	2.00+02		3.42–01		2.90+01	4.27–01		2.98+01		9.76–02
	3.00+02		2.42–01		3.03+01	4.59–01		3.11+01		1.02–01
	4.00+02		1.90–01		3.11+01	4.80–01		3.18+01		1.04–01
	5.00+02		1.57–01		3.16+01	4.94–01		3.23+01		1.06–01
	6.00+02		1.34–01		3.20+01	5.04–01		3.26+01		1.07–01
	8.00+02		1.05–01		3.24+01	5.18–01		3.31+01		1.08–01
	1.00+03		8.64–02		3.27+01	5.27–01		3.34+01		1.09–01
	1.50+03		6.04–02		3.32+01	5.40–01		3.38+01		1.11–01
	2.00+03		4.67–02		3.34+01	5.48–01		3.40+01		1.11–01
	3.00+03		3.25–02		3.37+01	5.56–01		3.43+01		1.12–01
	4.00+03		2.51–02		3.38+01	5.60–01		3.44+01		1.13–01
	5.00+03		2.05–02		3.39+01	5.63–01		3.45+01		1.13–01
	6.00+03		1.74–02		3.40+01	5.65–01		3.45+01		1.13–01
	8.00+03		1.34–02		3.40+01	5.68–01		3.46+01		1.13–01
	1.00+04		1.09–02		3.41+01	5.70–01		3.47+01		1.14–01
	1.50+04		7.56–03		3.41+01	5.72–01		3.47+01		1.14–01
	2.00+04		5.81–03		3.42+01	5.73–01		3.48+01		1.14–01
	3.00+04		4.01–03		3.42+01	5.75–01		3.48+01		1.14–01
	4.00+04		3.08–03		3.42+01	5.76–01		3.48+01		1.14–01
	5.00+04		2.51–03		3.43+01	5.76–01		3.48+01		1.14–01
	6.00+04		2.12–03		3.43+01	5.76–01		3.48+01		1.14–01
	8.00+04		1.62–03		3.43+01	5.77–01		3.48+01		1.14–01
	1.00+05		1.32–03		3.43+01	5.77–01		3.48+01		1.14–01

(b/atom) x .003276 = cm^2/g

Table 3.—22. LEAD, Z=82

	Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent	Total: With coherent	Total: Without coherent
	MeV	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*b/atom*	*cm²/g*	*cm²/g*
	1.00–02	1.73+03	5.25+01	4.40+04			4.57+04	4.41+04	1.33+02	1.28+02
	1.30–02	1.34+03	5.19+01	2.20+04			2.33+04	2.20+04	6.78+01	6.41+01
L_3	1.30–02	1.34+03	5.19+01	5.58+04			5.71+04	5.59+04	1.66+02	1.62+02
	1.50–02	1.15+03	5.16+01	3.84+04			3.96+04	3.85+04	1.15+02	1.12+02
	1.52–02	1.13+03	5.15+01	3.75+04			3.86+04	3.76+04	1.12+02	1.09+02
L_2	1.52–02	1.13+03	5.15+01	4.90+04			5.01+04	4.91+04	1.46+02	1.43+02
	1.59–02	1.08+03	5.14+01	4.35+04			4.46+04	4.36+04	1.30+02	1.27+02
L_1	1.59–02	1.08+03	5.14+01	5.29+04			5.40+04	5.29+04	1.57+02	1.54+02
	2.00–02	8.17+02	5.07+01	2.86+04			2.95+04	2.87+04	8.57+01	8.34+01
	3.00–02	4.91+02	4.90+01	9.71+03			1.02+04	9.76+03	2.97+01	2.84+01
	4.00–02	3.36+02	4.75+01	4.47+03			4.81+03	4.52+03	1.40+01	1.31+01
	5.00–02	2.48+02	4.60+01	2.44+03			2.68+03	2.48+03	7.81+00	7.22+00
	6.00–02	1.94+02	4.47+01	1.48+03			1.67+03	1.52+03	4.87+00	4.43+00
	8.00–02	1.32+02	4.24+01	6.70+02			8.03+02	7.13+02	2.33+00	2.07+00
	8.80–02	1.16+02	4.16+01	5.15+02			6.31+02	5.56+02	1.83+00	1.62+00
K	8.80–02	1.16+02	4.16+01	2.45+03			2.56+03	2.49+03	7.45+00	7.23+00
	1.00–01	9.93+01	4.04+01	1.76+03			1.86+03	1.80+03	5.40+00	5.23+00
	1.50–01	6.39+01	3.64+01	6.14+02			6.78+02	6.51+02	1.97+00	1.89+00
	2.00–01	4.92+01	3.33+01	2.92+02			3.41+02	3.25+02	9.91–01	9.45–01
	3.00–01	3.61+01	2.90+01	1.03+02			1.39+02	1.32+02	4.04–01	3.83–01
	4.00–01	3.00+01	2.60+01	4.96+01			7.96+01	7.56+01	2.31–01	2.20–01
	5.00–01	2.63+01	2.37+01	2.92+01			5.55+01	5.29+01	1.61–01	1.54–01
	6.00–01	2.37+01	2.19+01	1.92+01			4.29+01	4.11+01	1.25–01	1.20–01
	8.00–01	2.03+01	1.93+01	1.02+01			3.04+01	2.95+01	8.85–02	8.56–02
	1.00+00	1.79+01	1.73+01	6.39+00			2.43+01	2.37+01	7.08–02	6.90–02
	1.50+00	1.43+01	1.41+01	2.89+00	5.66–01		1.78+01	1.75+01	5.17–02	5.10–02
	2.00+00	1.22+01	1.20+01	1.77+00	1.70+00		1.57+01	1.55+01	4.55–02	4.50–02
	3.00+00	9.51+00	9.46+00	9.14–01	3.94+00	3.30–03	1.44+01	1.43+01	4.18–02	4.16–02
	4.00+00	7.94+00	7.89+00	5.89–01	5.77+00	1.35–02	1.43+01	1.43+01	4.16–02	4.14–02
	5.00+00	6.84+00	6.81+00	4.34–01	7.30+00	2.66–02	1.46+01	1.46+01	4.24–02	4.24–02
	6.00+00	6.04+00	6.02+00	3.36–01	8.54+00	4.09–02	1.50+01	1.49+01	4.35–02	4.34–02
	8.00+00	4.93+00	4.92+00	2.31–01	1.05+01	7.00–02	1.58+01	1.58+01	4.59–02	4.59–02
	1.00+01	4.20+00	4.19+00	1.78–01	1.22+01	9.57–02	1.67+01	1.67+01	4.84–02	4.84–02
	1.50+01		3.10+00	1.12–01	1.55+01	1.48–01		1.89+01		5.48–02
	2.00+01		2.49+00	8.10–02	1.81+01	1.86–01		2.09+01		6.06–02
	3.00+01		1.81+00	5.20–02	2.18+01	2.42–01		2.39+01		6.96–02
	4.00+01		1.44+00	3.80–02	2.43+01	2.81–01		2.60+01		7.57–02
	5.00+01		1.20+00	3.00–02	2.61+01	3.11–01		2.77+01		8.04–02
	6.00+01		1.04+00	2.50–02	2.75+01	3.35–01		2.89+01		8.41–02
	8.00+01		8.18–01	1.80–02	2.96+01	3.71–01		3.08+01		8.96–02
	1.00+02		6.79–01	1.41–02	3.10+01	3.97–01		3.21+01		9.34–02
	1.50+02		4.83–01		3.33+01	4.41–01		3.43+01		9.96–02
	2.00+02		3.79–01		3.48+01	4.68–01		3.56+01		1.03–01
	3.00+02		2.69–01		3.64+01	5.03–01		3.71+01		1.08–01
	4.00+02		2.10–01		3.73+01	5.25–01		3.80+01		1.11–01
	5.00+02		1.74–01		3.79+01	5.40–01		3.86+01		1.12–01
	6.00+02		1.49–01		3.83+01	5.51–01		3.90+01		1.13–01
	8.00+02		1.16–01		3.89+01	5.66–01		3.96+01		1.15–01
	1.00+03		9.58–02		3.92+01	5.76–01		3.99+01		1.16–01
	1.50+03		6.69–02		3.98+01	5.90–01		4.04+01		1.18–01
	2.00+03		5.18–02		4.00+01	5.98–01		4.07+01		1.18–01
	3.00+03		3.60–02		4.04+01	6.07–01		4.10+01		1.19–01
	4.00+03		2.78–02		4.05+01	6.12–01		4.12+01		1.20–01
	5.00+03		2.27–02		4.06+01	6.15–01		4.13+01		1.20–01
	6.00+03		1.93–02		4.07+01	6.17–01		4.13+01		1.20–01
	8.00+03		1.48–02		4.08+01	6.20–01		4.14+01		1.20–01
	1.00+04		1.21–02		4.09+01	6.21–01		4.15+01		1.21–01
	1.50+04		8.37–03		4.09+01	6.24–01		4.16+01		1.21–01
	2.00+04		6.44–03		4.10+01	6.25–01		4.16+01		1.21–01
	3.00+04		4.44–03		4.10+01	6.27–01		4.16+01		1.21–01
	4.00+04		3.41–03		4.10+01	6.28–01		4.17+01		1.21–01
	5.00+04		2.78–03		4.11+01	6.28–01		4.17+01		1.21–01
	6.00+04		2.35–03		4.11+01	6.28–01		4.17+01		1.21–01
	8.00+04		1.80–03		4.11+01	6.29–01		4.17+01		1.21–01
	1.00+05		1.46–03		4.11+01	6.29–01		4.17+01		1.21–01

(b/atom) x .002907 = cm²/g

Table 3.-23. URANIUM, Z=92

	Photon energy	Scattering With coherent	Scattering Without coherent	Photo-electric	Pair production Nuclear field	Pair production Electron field	Total With coherent	Total Without coherent	Total With coherent	Total Without coherent
	MeV	b/atom	b/atom	b/atom	b/atom	b/atom	b/atom	b/atom	cm²/g	cm²/g
	1.00-02	2.17+03	5.89+01	6.84+04			7.05+04	6.84+04	1.78+02	1.73+02
	1.50-02	1.47+03	5.79+01	2.38+04			2.53+04	2.38+04	6.39+01	6.03+01
	1.72-02	1.27+03	5.74+01	1.68+04			1.81+04	1.69+04	4.58+01	4.28+01
L_3	1.72-02	1.27+03	5.74+01	4.06+04			4.19+04	4.07+04	1.06+02	1.03+02
	2.00-02	1.07+03	5.68+01	2.70+04			2.81+04	2.71+04	7.10+01	6.85+01
	2.09-02	1.01+03	5.67+01	2.38+04			2.48+04	2.38+04	6.27+01	6.03+01
L_2	2.09-02	1.01+03	5.67+01	3.38+04			3.48+04	3.38+04	8.80+01	8.56+01
	2.18-02	9.61+02	5.65+01	3.06+04			3.15+04	3.06+04	7.98+01	7.75+01
L_1	2.18-02	9.61+02	5.65+01	3.53+04			3.63+04	3.54+04	9.18+01	8.95+01
	3.00-02	6.36+02	5.50+01	1.56+04			1.62+04	1.56+04	4.10+01	3.96+01
	4.00-02	4.36+02	5.32+01	7.35+03			7.79+03	7.40+03	1.97+01	1.87+01
	5.00-02	3.22+02	5.16+01	4.07+03			4.39+03	4.12+03	1.11+01	1.04+01
	6.00-02	2.51+02	5.02+01	2.50+03			2.75+03	2.55+03	6.96+00	6.45+00
	8.00-02	1.68+02	4.76+01	1.16+03			1.32+03	1.20+03	3.35+00	3.04+00
	1.00-01	1.25+02	4.53+01	6.31+02			7.56+02	6.77+02	1.91+00	1.71+00
	1.16-01	1.05+02	4.38+01	4.26+02			5.31+02	4.70+02	1.34+00	1.19+00
K	1.16-01	1.05+02	4.38+01	1.82+03			1.92+03	1.86+03	4.86+00	4.71+00
	1.50-01	7.80+01	4.08+01	9.36+02			1.01+03	9.77+02	2.56+00	2.47+00
	2.00-01	5.88+01	3.74+01	4.48+02			5.07+02	4.85+02	1.28+00	1.23+00
	3.00-01	4.21+01	3.25+01	1.59+02			2.01+02	1.92+02	5.09-01	4.85-01
	4.00-01	3.45+01	2.91+01	7.87+01			1.13+02	1.08+02	2.86-01	2.73-01
	5.00-01	3.01+01	2.66+01	4.64+01			7.65+01	7.30+01	1.93-01	1.85-01
	6.00-01	2.70+01	2.46+01	3.06+01			5.76+01	5.52+01	1.46-01	1.40-01
	8.00-01	2.29+01	2.16+01	1.65+01			3.94+01	3.81+01	9.97-02	9.64-02
	1.00+00	2.03+01	1.94+01	1.04+01			3.07+01	2.98+01	7.76-02	7.54-02
	1.50+00	1.61+01	1.58+01	4.73+00	7.77-01		2.17+01	2.13+01	5.48-02	5.39-02
	2.00+00	1.37+01	1.35+01	2.84+00	2.26+00		1.88+01	1.86+01	4.75-02	4.70-02
	3.00+00	1.07+01	1.06+01	1.49+00	5.09+00	3.70-03	1.73+01	1.72+01	4.38-02	4.35-02
	4.00+00	8.91+00	8.85+00	9.58-01	7.32+00	1.52-02	1.72+01	1.71+01	4.35-02	4.34-02
	5.00+00	7.68+00	7.64+00	7.02-01	9.16+00	2.99-02	1.76+01	1.75+01	4.45-02	4.44-02
	6.00+00	6.78+00	6.75+00	5.43-01	1.06+01	4.59-02	1.80+01	1.80+01	4.55-02	4.54-02
	8.00+00	5.55+00	5.52+00	3.75-01	1.30+01	7.86-02	1.90+01	1.89+01	4.80-02	4.79-02
	1.00+01	4.72+00	4.71+00	2.88-01	1.49+01	1.07-01	2.00+01	2.00+01	5.06-02	5.06-02
	1.50+01		3.48+00	1.80-01	1.88+01	1.65-01		2.27+01		5.73-02
	2.00+01		2.80+00	1.31-01	2.20+01	2.08-01		2.51+01		6.36-02
	3.00+01		2.04+00	8.50-02	2.66+01	2.69-01		2.90+01		7.33-02
	4.00+01		1.62+00	6.20-02	2.96+01	3.13-01		3.16+01		7.99-02
	5.00+01		1.35+00	5.00-02	3.18+01	3.46-01		3.36+01		8.50-02
	6.00+01		1.16+00	4.00-02	3.36+01	3.73-01		3.51+01		8.89-02
	8.00+01		9.17-01	3.00-02	3.61+01	4.12-01		3.75+01		9.48-02
	1.00+02		7.62-01	2.40-02	3.77+01	4.41-01		3.89+01		9.84-02
	1.50+02		5.42-01		4.07+01	4.89-01		4.17+01		1.06-01
	2.00+02		4.25-01		4.24+01	5.19-01		4.34+01		1.10-01
	3.00+02		3.01-01		4.44+01	5.57-01		4.53+01		1.15-01
	4.00+02		2.36-01		4.56+01	5.81-01		4.64+01		1.17-01
	5.00+02		1.95-01		4.63+01	5.98-01		4.71+01		1.19-01
	6.00+02		1.67-01		4.69+01	6.09-01		4.76+01		1.21-01
	8.00+02		1.31-01		4.75+01	6.25-01		4.83+01		1.22-01
	1.00+03		1.07-01		4.80+01	6.36-01		4.88+01		1.23-01
	1.50+03		7.50-02		4.87+01	6.51-01		4.94+01		1.25-01
	2.00+03		5.81-02		4.90+01	6.60-01		4.97+01		1.26-01
	3.00+03		4.04-02		4.94+01	6.69-01		5.01+01		1.27-01
	4.00+03		3.12-02		4.96+01	6.74-01		5.03+01		1.27-01
	5.00+03		2.55-02		4.97+01	6.78-01		5.04+01		1.28-01
	6.00+03		2.16-02		4.98+01	6.80-01		5.05+01		1.28-01
	8.00+03		1.67-02		5.00+01	6.83-01		5.07+01		1.28-01
	1.00+04		1.36-02		5.00+01	6.85-01		5.07+01		1.28-01
	1.50+04		9.40-03		5.01+01	6.88-01		5.08+01		1.29-01
	2.00+04		7.22-03		5.02+01	6.89-01		5.09+01		1.29-01
	3.00+04		4.98-03		5.02+01	6.91-01		5.09+01		1.29-01
	4.00+04		3.83-03		5.03+01	6.92-01		5.10+01		1.29-01
	5.00+04		3.11-03		5.03+01	6.92-01		5.10+01		1.29-01
	6.00+04		2.63-03		5.03+01	6.92-01		5.10+01		1.29-01
	8.00+04		2.02-03		5.03+01	6.93-01		5.10+01		1.29-01
	1.00+05		1.64-03		5.04+01	6.93-01		5.11+01		1.29-01

(b/atom) x .002530 = cm²/g

Table 3.—24. WATER, H_2O

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00—02	3.97—01	2.14—01	4.78+00			5.18+00	4.99+00
1.50—02	3.09—01	2.10—01	1.27+00			1.58+00	1.48+00
2.00—02	2.70—01	2.07—01	5.05—01			7.75—01	7.11—01
3.00—02	2.32—01	2.00—01	1.38—01			3.70—01	3.38—01
4.00—02	2.13—01	1.93—01	5.48—02			2.67—01	2.48—01
5.00—02	2.00—01	1.88—01	2.67—02			2.27—01	2.14—01
6.00—02	1.91—01	1.82—01	1.50—02			2.06—01	1.97—01
8.00—02	1.78—01	1.73—01	5.95—03			1.84—01	1.79—01
1.00—01	1.68—01	1.65—01	2.85—03			1.71—01	1.68—01
1.50—01	1.50—01	1.48—01	7.76—04			1.51—01	1.49—01
2.00—01	1.37—01	1.36—01	3.11—04			1.37—01	1.36—01
3.00—01	1.19—01	1.18—01	8.86—05			1.19—01	1.18—01
4.00—01	1.06—01	1.06—01	3.78—05			1.06—01	1.06—01
5.00—01	9.68—02	9.67—02	2.04—05			9.68—02	9.67—02
6.00—01	8.96—02	8.95—02	1.28—05			8.96—02	8.95—02
8.00—01		7.86—02	6.42—06				7.86—02
1.00+00		7.06—02	3.98—06				7.07—02
1.50+00		5.74—02	1.86—06	9.86—05			5.75—02
2.00+00		4.90—02	1.18—06	3.93—04			4.94—02
3.00+00		3.85—02	6.62—07	1.13—03	1.34—05		3.97—02
4.00+00		3.22—02	4.51—07	1.83—03	5.52—05		3.40—02
5.00+00		2.78—02	3.44—07	2.45—03	1.09—04		3.03—02
6.00+00		2.45—02	2.75—07	3.00—03	1.67—04		2.77—02
8.00+00		2.01—02	1.97—07	3.93—03	2.86—04		2.43—02
1.00+01		1.71—02	1.54—07	4.69—03	3.90—04		2.22—02
1.50+01		1.27—02		6.11—03	6.08—04		1.94—02
2.00+01		1.02—02		7.16—03	7.80—04		1.81—02
3.00+01		7.40—03		8.63—03	1.04—03		1.71—02
4.00+01		5.88—03		9.63—03	1.23—03		1.67—02
5.00+01		4.91—03		1.04—02	1.38—03		1.67—02
6.00+01		4.22—03		1.10—02	1.51—03		1.67—02
8.00+01		3.33—03		1.19—02	1.70—03		1.70—02
1.00+02		2.77—03		1.26—02	1.84—03		1.72—02
1.50+02		1.97—03		1.37—02	2.09—03		1.78—02
2.00+02		1.54—03		1.44—02	2.26—03		1.82—02
3.00+02		1.09—03		1.52—02	2.48—03		1.88—02
4.00+02		8.57—04		1.57—02	2.62—03		1.92—02
5.00+02		7.10—04		1.60—02	2.73—03		1.95—02
6.00+02		6.08—04		1.63—02	2.80—03		1.97—02
8.00+02		4.75—04		1.66—02	2.92—03		2.00—02
1.00+03		3.90—04		1.68—02	3.00—03		2.02—02
1.50+03		2.73—04		1.71—02	3.12—03		2.05—02
2.00+03		2.11—04		1.72—02	3.20—03		2.06—02
3.00+03		1.47—04		1.74—02	3.30—03		2.08—02
4.00+03		1.13—04		1.75—02	3.35—03		2.10—02
5.00+03		9.26—05		1.76—02	3.38—03		2.10—02
6.00+03		7.86—05		1.76—02	3.40—03		2.11—02
8.00+03		6.05—05		1.77—02	3.43—03		2.11—02
1.00+04		4.94—05		1.77—02	3.45—03		2.12—02
1.50+04		3.41—05		1.77—02	3.48—03		2.13—02
2.00+04		2.62—05		1.78—02	3.50—03		2.13—02
3.00+04		1.81—05		1.78—02	3.52—03		2.13—02
4.00+04		1.39—05		1.78—02	3.52—03		2.13—02
5.00+04		1.13—05		1.78—02	3.53—03		2.13—02
6.00+04		9.57—06		1.78—02	3.53—03		2.14—02
8.00+04		7.33—06		1.78—02	3.54—03		2.14—02
1.00+05		5.97—06		1.78—02	3.54—03		2.14—02

Table 3.–25. SILICON DIOXIDE, SiO_2

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g
1.00–02	5.64–01	1.93–01	1.85+01			1.90+01	1.87+01
1.50–02	3.95–01	1.89–01	5.33+00			5.73+00	5.52+00
2.00–02	3.16–01	1.86–01	2.18+00			2.49+00	2.36+00
3.00–02	2.46–01	1.80–01	6.13–01			8.59–01	7.93–01
4.00–02	2.14–01	1.74–01	2.48–01			4.63–01	4.22–01
5.00–02	1.96–01	1.69–01	1.22–01			3.18–01	2.91–01
6.00–02	1.83–01	1.64–01	6.91–02			2.52–01	2.33–01
8.00–02	1.67–01	1.56–01	2.78–02			1.94–01	1.83–01
1.00–01	1.55–01	1.48–01	1.36–02			1.69–01	1.62–01
1.50–01	1.37–01	1.33–01	3.76–03			1.40–01	1.37–01
2.00–01	1.24–01	1.22–01	1.53–03			1.26–01	1.24–01
3.00–01	1.07–01	1.06–01	4.45–04			1.08–01	1.07–01
4.00–01	9.57–02	9.52–02	1.92–04			9.59–02	9.54–02
5.00–01	8.73–02	8.70–02	1.04–04			8.74–02	8.71–02
6.00–01	8.07–02	8.05–02	6.50–05			8.08–02	8.05–02
8.00–01		7.07–02	3.28–05				7.07–02
1.00+00		6.36–02	2.03–05				6.36–02
1.50+00		5.16–02	9.49–06	1.47–04			5.18–02
2.00+00		4.41–02	6.02–06	5.81–04			4.47–02
3.00+00		3.47–02	3.33–06	1.66–03	1.21–05		3.63–02
4.00+00		2.89–02	2.26–06	2.69–03	4.97–05		3.17–02
5.00+00		2.50–02	1.63–06	3.60–03	9.76–05		2.87–02
6.00+00		2.21–02	1.38–06	4.42–03	1.50–04		2.66–02
8.00+00		1.81–02	9.81–07	5.76–03	2.57–04		2.41–02
1.00+01		1.54–02	7.68–07	6.86–03	3.51–04		2.26–02
1.50+01		1.14–02		8.94–03	5.47–04		2.09–02
2.00+01		9.14–03		1.05–02	7.02–04		2.03–02
3.00+01		6.65–03		1.26–02	9.35–04		2.02–02
4.00+01		5.28–03		1.40–02	1.11–03		2.04–02
5.00+01		4.41–03		1.52–02	1.24–03		2.08–02
6.00+01		3.80–03		1.60–02	1.35–03		2.12–02
8.00+01		3.00–03		1.73–02	1.51–03		2.18–02
1.00+02		2.49–03		1.83–02	1.64–03		2.24–02
1.50+02		1.77–03		1.98–02	1.85–03		2.34–02
2.00+02		1.39–03		2.07–02	1.99–03		2.41–02
3.00+02		9.85–04		2.19–02	2.18–03		2.50–02
4.00+02		7.71–04		2.25–02	2.30–03		2.56–02
5.00+02		6.39–04		2.29–02	2.38–03		2.60–02
6.00+02		5.47–04		2.33–02	2.45–03		2.62–02
8.00+02		4.27–04		2.37–02	2.54–03		2.66–02
1.00+03		3.51–04		2.39–02	2.61–03		2.69–02
1.50+03		2.45–04		2.43–02	2.71–03		2.73–02
2.00+03		1.90–04		2.45–02	2.78–03		2.75–02
3.00+03		1.32–04		2.48–02	2.85–03		2.78–02
4.00+03		1.02–04		2.49–02	2.89–03		2.79–02
5.00+03		8.33–05		2.50–02	2.92–03		2.80–02
6.00+03		7.06–05		2.50–02	2.94–03		2.81–02
8.00+03		5.44–05		2.51–02	2.97–03		2.81–02
1.00+04		4.44–05		2.52–02	2.98–03		2.82–02
1.50+04		3.07–05		2.52–02	3.01–03		2.83–02
2.00+04		2.36–05		2.53–02	3.02–03		2.83–02
3.00+04		1.63–05		2.53–02	3.03–03		2.83–02
4.00+04		1.25–05		2.53–02	3.04–03		2.84–02
5.00+04		1.02–05		2.53–02	3.04–03		2.84–02
6.00+04		8.60–06		2.53–02	3.05–03		2.84–02
8.00+04		6.60–06		2.53–02	3.05–03		2.84–02
1.00+05		5.37–06		2.54–02	3.05–03		2.84–02

Table 3.—26. SODIUM IODIDE, NaI

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00—02	2.53+00	1.65—01	1.36+02			1.39+02	1.36+02
1.50—02	1.69+00	1.62—01	4.57+01			4.74+01	4.59+01
2.00—02	1.23+00	1.59—01	2.11+01			2.23+01	2.12+01
3.00—02	7.48—01	1.54—01	6.70+00			7.45+00	6.86+00
3.32—02	6.60—01	1.52—01	5.03+00			5.69+00	5.19+00
*3.32—02	6.60—01	1.52—01	3.03+01			3.09+01	3.04+01
4.00—02	5.28—01	1.49—01	1.88+01			1.93+01	1.89+01
5.00—02	4.10—01	1.44—01	1.03+01			1.07+01	1.05+01
6.00—02	3.36—01	1.40—01	6.28+00			6.62+00	6.42+00
8.00—02	2.49—01	1.33—01	2.87+00			3.12+00	3.00+00
1.00—01	2.02—01	1.27—01	1.52+00			1.72+00	1.64+00
1.50—01	1.49—01	1.14—01	4.76—01			6.25—01	5.90—01
2.00—01	1.24—01	1.05—01	2.09—01			3.34—01	3.14—01
3.00—01	9.99—02	9.09—02	6.68—02			1.67—01	1.58—01
4.00—01	8.64—02	8.15—02	3.10—02			1.17—01	1.12—01
5.00—01	7.78—02	7.44—02	1.77—02			9.55—02	9.21—02
6.00—01	7.12—02	6.88—02	1.14—02			8.26—02	8.02—02
8.00—01	6.17—02	6.05—02	5.88—03			6.76—02	6.63—02
1.00+00	5.49—02	5.43—02	3.66—03			5.86—02	5.80—02
1.50+00	4.45—02	4.42—02	1.66—03	7.36—04		4.69—02	4.66—02
2.00+00	3.78—02	3.77—02	1.02—03	2.49—03		4.13—02	4.12—02
3.00+00	2.97—02	2.97—02	5.46—04	6.40—03	1.03—05	3.66—02	3.66—02
4.00+00	2.48—02	2.47—02	3.61—04	9.89—03	4.25—05	3.51—02	3.50—02
5.00+00		2.14—02	2.70—04	1.29—02	8.35—05		3.46—02
6.00+00		1.89—02	2.11—04	1.55—02	1.28—04		3.47—02
8.00+00		1.54—02	1.47—04	1.97—02	2.20—04		3.55—02
1.00+01		1.32—02	1.13—04	2.32—02	3.00—04		3.68—02
1.50+01		9.73—03	7.08—05	2.99—02	4.68—04		4.02—02
2.00+01		7.81—03	5.14—05	3.49—02	5.97—04		4.33—02
3.00+01		5.69—03	3.31—05	4.18—02	7.82—04		4.84—02
4.00+01		4.52—03	2.45—05	4.65—02	9.13—04		5.20—02
5.00+01		3.77—03	1.94—05	5.00—02	1.01—03		5.48—02
6.00+01		3.25—03	1.60—05	5.28—02	1.09—03		5.71—02
8.00+01		2.56—03	1.19—05	5.67—02	1.22—03		6.05—02
1.00+02		2.13—03	9.52—06	5.95—02	1.31—03		6.29—02
1.50+02		1.52—03		6.40—02	1.46—03		6.70—02
2.00+02		1.19—03		6.67—02	1.56—03		6.95—02
3.00+02		8.42—04		6.99—02	1.69—03		7.24—02
4.00+02		6.59—04		7.17—02	1.77—03		7.41—02
5.00+02		5.46—04		7.28—02	1.82—03		7.52—02
6.00+02		4.68—04		7.37—02	1.87—03		7.60—02
8.00+02		3.65—04		7.49—02	1.92—03		7.71—02
1.00+03		3.00—04		7.55—02	1.96—03		7.78—02
1.50+03		2.10—04		7.66—02	2.02—03		7.89—02
2.00+03		1.62—04		7.72—02	2.06—03		7.94—02
3.00+03		1.13—04		7.78—02	2.09—03		8.00—02
4.00+03		8.71—05		7.81—02	2.11—03		8.03—02
5.00+03		7.12—05		7.83—02	2.13—03		8.05—02
6.00+03		6.04—05		7.85—02	2.14—03		8.07—02
8.00+03		4.65—05		7.86—02	2.15—03		8.08—02
1.00+04		3.80—05		7.87—02	2.16—03		8.09—02
1.50+04		2.63—05		7.89—02	2.17—03		8.11—02
2.00+04		2.02—05		7.90—02	2.18—03		8.12—02
3.00+04		1.39—05		7.91—02	2.18—03		8.13—02
4.00+04		1.07—05		7.91—02	2.19—03		8.13—02
5.00+04		8.70—06		7.92—02	2.19—03		8.14—02
6.00+04		7.36—06		7.92—02	2.19—03		8.14—02
8.00+04		5.64—06		7.93—02	2.19—03		8.15—02
1.00+05		4.59—06		7.93—02	2.19—03		8.15—02

*Iodine K-edge.

Table 3.–27. AIR, NBS Handbook 85(1964) Composition

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00–02	3.64–01	1.93–01	4.63+00			4.99+00	4.82+00
1.50–02	2.85–01	1.89–01	1.27+00			1.55+00	1.45+00
2.00–02	2.47–01	1.86–01	5.05–01			7.52–01	6.91–01
3.00–02	2.11–01	1.80–01	1.39–01			3.49–01	3.18–01
4.00–02	1.93–01	1.74–01	5.53–02			2.48–01	2.29–01
5.00–02	1.81–01	1.69–01	2.70–02			2.08–01	1.96–01
6.00–02	1.73–01	1.64–01	1.52–02			1.88–01	1.79–01
8.00–02	1.61–01	1.56–01	6.06–03			1.67–01	1.62–01
1.00–01	1.51–01	1.48–01	2.94–03			1.54–01	1.51–01
1.50–01	1.35–01	1.33–01	8.05–04			1.36–01	1.34–01
2.00–01	1.23–01	1.22–01	3.24–04			1.23–01	1.23–01
3.00–01	1.07–01	1.06–01	9.30–05			1.07–01	1.06–01
4.00–01	9.53–02	9.52–02	3.99–05			9.54–02	9.53–02
5.00–01	8.70–02	8.70–02	2.15–05			8.70–02	8.70–02
6.00–01	8.05–02	8.04–02	1.34–05			8.05–02	8.05–02
8.00–01		7.07–02	6.79–06				7.07–02
1.00+00		6.36–02	4.20–06				6.36–02
1.50+00		5.17–02	1.96–06	9.89–05			5.18–02
2.00+00		4.41–02	1.25–06	3.94–04			4.45–02
3.00+00		3.47–02	6.97–07	1.13–03	1.21–05		3.58–02
4.00+00		2.89–02	4.73–07	1.83–03	4.97–05		3.08–02
5.00+00		2.50–02	3.61–07	2.46–03	9.76–05		2.75–02
6.00+00		2.21–02	2.88–07	3.01–03	1.50–04		2.52–02
8.00+00		1.81–02	2.06–07	3.94–03	2.57–04		2.23–02
1.00+01		1.54–02	1.61–07	4.70–03	3.51–04		2.04–02
1.50+01		1.14–02		6.14–03	5.47–04		1.81–02
2.00+01		9.14–03		7.18–03	7.02–04		1.70–02
3.00+01		6.65–03		8.65–03	9.35–04		1.62–02
4.00+01		5.28–03		9.67–03	1.11–03		1.61–02
5.00+01		4.41–03		1.04–02	1.24–03		1.61–02
6.00+01		3.80–03		1.11–02	1.36–03		1.62–02
8.00+01		3.00–03		1.20–02	1.53–03		1.65–02
1.00+02		2.55–03		1.26–02	1.65–03		1.68–02
1.50+02		1.77–03		1.38–02	1.87–03		1.74–02
2.00+02		1.39–03		1.45–02	2.02–03		1.79–02
3.00+02		9.85–04		1.53–02	2.22–03		1.85–02
4.00+02		7.71–04		1.58–02	2.34–03		1.89–02
5.00+02		6.38–04		1.61–02	2.43–03		1.92–02
6.00+02		5.47–04		1.63–02	2.50–03		1.94–02
8.00+02		4.27–04		1.67–02	2.60–03		1.97–02
1.00+03		3.51–04		1.69–02	2.67–03		1.99–02
1.50+03		2.45–04		1.72–02	2.79–03		2.02–02
2.00+03		1.90–04		1.73–02	2.86–03		2.04–02
3.00+03		1.32–04		1.75–02	2.95–03		2.06–02
4.00+03		1.02–04		1.76–02	2.99–03		2.07–02
5.00+03		8.33–05		1.77–02	3.02–03		2.08–02
6.00+03		7.07–05		1.77–02	3.05–03		2.08–02
8.00+03		5.44–05		1.78–02	3.08–03		2.09–02
1.00+04		4.44–05		1.78–02	3.10–03		2.09–02
1.50+04		3.07–05		1.78–02	3.12–03		2.10–02
2.00+04		2.36–05		1.79–02	3.14–03		2.10–02
3.00+04		1.63–05		1.79–02	3.15–03		2.11–02
4.00+04		1.25–05		1.79–02	3.16–03		2.11–02
5.00+04		1.02–05		1.79–02	3.17–03		2.11–02
6.00+04		8.60–06		1.79–02	3.17–03		2.11–02
8.00+04		6.60–06		1.79–02	3.18–03		2.11–02
1.00+05		5.37–06		1.79–02	3.18–03		2.11–02

Table 3.—28. CONCRETE, Grodstein—McGinnies Composition

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00—02	6.00—01	1.93—01	2.63+01			2.69+01	2.65+01
1.50—02	4.21—01	1.89—01	7.82+00			8.24+00	8.01+00
2.00—02	3.34—01	1.86—01	3.26+00			3.59+00	3.45+00
3.00—02	2.56—01	1.80—01	9.38—01			1.19+00	1.12+00
4.00—02	2.20—01	1.74—01	3.84—01			6.05—01	5.59—01
5.00—02	2.00—01	1.69—01	1.92—01			3.92—01	3.61—01
6.00—02	1.86—01	1.64—01	1.09—01			2.95—01	2.73—01
8.00—02	1.69—01	1.56—01	4.45—02			2.13—01	2.00—01
1.00—01	1.57—01	1.48—01	2.19—02			1.79—01	1.70—01
1.50—01	1.37—01	1.34—01	6.20—03			1.44—01	1.40—01
2.00—01	1.25—01	1.22—01	2.56—03			1.27—01	1.25—01
3.00—01	1.07—01	1.07—01	7.52—04			1.08—01	1.07—01
4.00—01	9.60—02	9.54—02	3.27—04			9.63—02	9.58—02
5.00—01	8.75—02	8.72—02	1.77—04			8.77—02	8.73—02
6.00—01	8.09—02	8.06—02	1.11—04			8.10—02	8.07—02
8.00—01	7.09—02	7.08—02	5.64—05			7.09—02	7.09—02
1.00+00		6.37—02	3.50—05				6.37—02
1.50+00		5.18—02	1.63—05	1.58—04			5.19—02
2.00+00		4.42—02	1.03—05	6.22—04			4.48—02
3.00+00		3.47—02	5.67—06	1.77—03	1.21—05		3.65—02
4.00+00		2.90—02	3.84—06	2.87—03	4.98—05		3.19—02
5.00+00		2.50—02	2.86—06	3.84—03	9.78—05		2.90—02
6.00+00		2.21—02	2.32—06	4.70—03	1.50—04		2.70—02
8.00+00		1.81—02	1.65—06	6.13—03	2.57—04		2.45—02
1.00+01		1.54—02	1.29—06	7.31—03	3.52—04		2.31—02
1.50+01		1.14—02	9.21—08	9.52—03	5.48—04		2.15—02
2.00+01		9.15—03	6.58—08	1.11—02	7.03—04		2.10—02
3.00+01		6.67—03		1.34—02	9.37—04		2.10—02
4.00+01		5.30—03		1.49—02	1.11—03		2.13—02
5.00+01		4.42—03		1.61—02	1.24—03		2.18—02
6.00+01		3.81—03		1.70—02	1.35—03		2.22—02
8.00+01		3.00—03		1.84—02	1.51—03		2.29—02
1.00+02		2.49—03		1.94—02	1.64—03		2.35—02
1.50+02		1.78—03		2.11—02	1.85—03		2.47—02
2.00+02		1.39—03		2.20—02	1.99—03		2.54—02
3.00+02		9.87—04		2.32—02	2.18—03		2.64—02
4.00+02		7.73—04		2.39—02	2.30—03		2.69—02
5.00+02		6.40—04		2.43—02	2.38—03		2.73—02
6.00+02		5.48—04		2.47—02	2.44—03		2.76—02
8.00+02		4.28—04		2.51—02	2.54—03		2.81—02
1.00+03		3.52—04		2.54—02	2.60—03		2.83—02
1.50+03		2.46—04		2.58—02	2.71—03		2.87—02
2.00+03		1.90—04		2.60—02	2.77—03		2.90—02
3.00+03		1.32—04		2.63—02	2.85—03		2.92—02
4.00+03		1.02—04		2.64—02	2.89—03		2.94—02
5.00+03		8.35—05		2.65—02	2.92—03		2.95—02
6.00+03		7.08—05		2.65—02	2.93—03		2.95—02
8.00+03		5.45—05		2.66—02	2.96—03		2.96—02
1.00+04		4.45—05		2.67—02	2.97—03		2.97—02
1.50+04		3.08—05		2.67—02	3.00—03		2.98—02
2.00+04		2.37—05		2.68—02	3.01—03		2.98—02
3.00+04		1.63—05		2.68—02	3.02—03		2.98—02
4.00+04		1.25—05		2.68—02	3.03—03		2.99—02
5.00+04		1.02—05		2.68—02	3.03—03		2.99—02
6.00+04		8.62—06		2.68—02	3.04—03		2.99—02
8.00+04		6.61—06		2.68—02	3.04—03		2.99—02
1.00+05		5.38—06		2.69—02	3.04—03		2.99—02

Table 3.–29. 0.8N H_2SO_4 SOLUTION

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00–02	4.03–01	2.13–01	5.36+00			5.76+00	5.57+00
1.50–02	3.13–01	2.10–01	1.45+00			1.76+00	1.66+00
2.00–02	2.72–01	2.06–01	5.78–01			8.49–01	7.84–01
3.00–02	2.32–01	1.99–01	1.59–01			3.91–01	3.58–01
4.00–02	2.13–01	1.93–01	6.32–02			2.76–01	2.56–01
5.00–02	2.00–01	1.87–01	3.10–02			2.31–01	2.18–01
6.00–02	1.91–01	1.82–01	1.74–02			2.08–01	1.99–01
8.00–02	1.78–01	1.72–01	6.92–03			1.85–01	1.79–01
1.00–01	1.68–01	1.64–01	3.33–03			1.71–01	1.68–01
1.50–01	1.49–01	1.48–01	9.11–04			1.50–01	1.49–01
2.00–01	1.36–01	1.35–01	3.67–04			1.37–01	1.36–01
3.00–01	1.18–01	1.18–01	1.05–04			1.18–01	1.18–01
4.00–01	1.06–01	1.06–01	4.49–05			1.06–01	1.06–01
5.00–01	9.65–02	9.64–02	2.43–05			9.65–02	9.64–02
6.00–01	8.93–02	8.92–02	1.52–05			8.93–02	8.92–02
8.00–01		7.83–02	7.64–06				7.83–02
1.00+00		7.04–02	4.73–06				7.04–02
1.50+00		5.72–02	2.22–06	1.00–04			5.73–02
2.00+00		4.88–02	1.41–06	3.99–04			4.92–02
3.00+00		3.84–02	7.85–07	1.15–03	1.34–05		3.96–02
4.00+00		3.21–02	5.35–07	1.86–03	5.51–05		3.40–02
5.00+00		2.77–02	4.08–07	2.49–03	1.08–04		3.03–02
6.00+00		2.45–02	3.25–07	3.05–03	1.66–04		2.77–02
8.00+00		2.00–02	2.33–07	3.99–03	2.85–04		2.43–02
1.00+01		1.70–02	1.82–07	4.76–03	3.89–04		2.22–02
1.50+01		1.26–02		6.21–03	6.06–04		1.94–02
2.00+01		1.01–02		7.27–03	7.78–04		1.82–02
3.00+01		7.37–03		8.77–03	1.04–03		1.72–02
4.00+01		5.86–03		9.78–03	1.23–03		1.69–02
5.00+01		4.89–03		1.06–02	1.38–03		1.68–02
6.00+01		4.21–03		1.12–02	1.50–03		1.69–02
8.00+01		3.32–03		1.21–02	1.69–03		1.71–02
1.00+02		2.76–03		1.28–02	1.83–03		1.74–02
1.50+02		1.96–03		1.39–02	2.08–03		1.80–02
2.00+02		1.54–03		1.46–02	2.25–03		1.84–02
3.00+02		1.09–03		1.55–02	2.47–03		1.90–02
4.00+02		8.55–04		1.60–02	2.61–03		1.94–02
5.00+02		7.08–04		1.63–02	2.72–03		1.97–02
6.00+02		6.06–04		1.65–02	2.79–03		1.99–02
8.00+02		4.73–04		1.68–02	2.91–03		2.02–02
1.00+03		3.89–04		1.70–02	2.98–03		2.04–02
1.50+03		2.72–04		1.73–02	3.11–03		2.07–02
2.00+03		2.10–04		1.75–02	3.19–03		2.09–02
3.00+03		1.46–04		1.77–02	3.28–03		2.11–02
4.00+03		1.13–04		1.78–02	3.33–03		2.12–02
5.00+03		9.23–05		1.78–02	3.37–03		2.13–02
6.00+03		7.83–05		1.79–02	3.39–03		2.13–02
8.00+03		6.03–05		1.79–02	3.42–03		2.14–02
1.00+04		4.92–05		1.79–02	3.44–03		2.14–02
1.50+04		3.40–05		1.80–02	3.47–03		2.15–02
2.00+04		2.62–05		1.80–02	3.49–03		2.15–02
3.00+04		1.80–05		1.81–02	3.50–03		2.16–02
4.00+04		1.39–05		1.81–02	3.51–03		2.16–02
5.00+04		1.13–05		1.81–02	3.52–03		2.16–02
6.00+04		9.54–06		1.81–02	3.52–03		2.16–02
8.00+04		7.31–06		1.81–02	3.52–03		2.16–02
1.00+05		5.95–06		1.81–02	3.53–03		2.16–02

Table 3.–30. COMPACT BONE, NBS Handbook 85(1964) Composition

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g	cm²/g
1.00–02	4.90–01	2.05–01	1.98+01			2.03+01	2.00+01
1.50–02	3.67–01	2.01–01	5.95+00			6.32+00	6.15+00
2.00–02	3.05–01	1.97–01	2.49+00			2.79+00	2.68+00
3.00–02	2.46–01	1.91–01	7.16–01			9.62–01	9.07–01
4.00–02	2.18–01	1.85–01	2.93–01			5.12–01	4.78–01
5.00–02	2.02–01	1.79–01	1.47–01			3.49–01	3.27–01
6.00–02	1.90–01	1.74–01	8.39–02			2.74–01	2.58–01
8.00–02	1.75–01	1.65–01	3.45–02			2.09–01	2.00–01
1.00–01	1.63–01	1.57–01	1.70–02			1.80–01	1.74–01
1.50–01	1.45–01	1.42–01	4.86–03			1.49–01	1.47–01
2.00–01	1.31–01	1.30–01	2.01–03			1.33–01	1.32–01
3.00–01	1.14–01	1.13–01	5.93–04			1.14–01	1.14–01
4.00–01	1.02–01	1.01–01	2.59–04			1.02–01	1.01–01
5.00–01	9.26–02	9.24–02	1.40–04			9.27–02	9.25–02
6.00–01	8.56–02	8.55–02	8.79–05			8.57–02	8.56–02
8.00–01	7.52–02	7.51–02	4.46–05			7.52–02	7.51–02
1.00+00	6.75–02	6.75–02	2.77–05			6.76–02	6.75–02
1.50+00		5.49–02	1.29–05	1.27–04			5.50–02
2.00+00		4.68–02	8.15–06	5.01–04			4.73–02
3.00+00		3.68–02	4.48–06	1.43–03	1.29–05		3.83–02
4.00+00		3.07–02	3.02–06	2.31–03	5.28–05		3.31–02
5.00+00		2.65–02	2.30–06	3.10–03	1.04–04		2.97–02
6.00+00		2.35–02	1.83–06	3.79–03	1.59–04		2.74–02
8.00+00		1.92–02	1.30–06	4.95–03	2.73–04		2.44–02
1.00+01		1.63–02	1.02–06	5.90–03	3.73–04		2.26–02
1.50+01		1.21–02		7.69–03	5.81–04		2.04–02
2.00+01		9.71–03		8.99–03	7.45–04		1.94–02
3.00+01		7.07–03		1.08–02	9.93–04		1.89–02
4.00+01		5.62–03		1.21–02	1.18–03		1.89–02
5.00+01		4.69–03		1.30–02	1.32–03		1.90–02
6.00+01		4.04–03		1.38–02	1.44–03		1.93–02
8.00+01		3.18–03		1.49–02	1.61–03		1.97–02
1.00+02		2.65–03		1.57–02	1.75–03		2.01–02
1.50+02		1.88–03		1.71–02	1.98–03		2.10–02
2.00+02		1.48–03		1.79–02	2.14–03		2.15–02
3.00+02		1.05–03		1.89–02	2.35–03		2.23–02
4.00+02		8.19–04		1.95–02	2.48–03		2.28–02
5.00+02		6.78–04		1.98–02	2.57–03		2.31–02
6.00+02		5.81–04		2.01–02	2.65–03		2.33–02
8.00+02		4.54–04		2.05–02	2.75–03		2.37–02
1.00+03		3.73–04		2.07–02	2.83–03		2.39–02
1.50+03		2.61–04		2.11–02	2.95–03		2.43–02
2.00+03		2.02–04		2.13–02	3.02–03		2.45–02
3.00+03		1.40–04		2.15–02	3.10–03		2.47–02
4.00+03		1.08–04		2.16–02	3.15–03		2.49–02
5.00+03		8.85–05		2.17–02	3.18–03		2.49–02
6.00+03		7.51–05		2.17–02	3.20–03		2.50–02
8.00+03		5.78–05		2.18–02	3.23–03		2.51–02
1.00+04		4.72–05		2.18–02	3.25–03		2.51–02
1.50+04		3.26–05		2.19–02	3.28–03		2.52–02
2.00+04		2.51–05		2.19–02	3.29–03		2.52–02
3.00+04		1.73–05		2.19–02	3.31–03		2.53–02
4.00+04		1.33–05		2.20–02	3.32–03		2.53–02
5.00+04		1.08–05		2.20–02	3.32–03		2.53–02
6.00+04		9.14–06		2.20–02	3.33–03		2.53–02
8.00+04		7.01–06		2.20–02	3.33–03		2.53–02
1.00+05		5.70–06		2.20–02	3.33–03		2.53–02

Table 3.–31. MUSCLE, Striated, NBS Handbook 85(1964) Composition

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00–02	3.89–01	2.12–01	4.88+00			5.27+00	5.09+00
1.50–02	3.05–01	2.08–01	1.32+00			1.63+00	1.53+00
2.00–02	2.66–01	2.05–01	5.26–01			7.93–01	7.31–01
3.00–02	2.29–01	1.98–01	1.44–01			3.73–01	3.42–01
4.00–02	2.10–01	1.92–01	5.73–02			2.68–01	2.49–01
5.00–02	1.98–01	1.86–01	2.81–02			2.27–01	2.14–01
6.00–02	1.90–01	1.81–01	1.58–02			2.05–01	1.97–01
8.00–02	1.76–01	1.71–01	6.31–03			1.83–01	1.78–01
1.00–01	1.67–01	1.63–01	3.04–03			1.70–01	1.66–01
1.50–01	1.49–01	1.47–01	8.32–04			1.49–01	1.48–01
2.00–01	1.35–01	1.35–01	3.35–04			1.36–01	1.35–01
3.00–01	1.18–01	1.17–01	9.59–05			1.18–01	1.17–01
4.00–01	1.05–01	1.05–01	4.11–05			1.05–01	1.05–01
5.00–01	9.59–02	9.58–02	2.22–05			9.60–02	9.59–02
6.00–01	8.88–02	8.87–02	1.39–05			8.88–02	8.87–02
8.00–01		7.79–02	6.99–06				7.79–02
1.00+00		7.00–02	4.33–06				7.00–02
1.50+00		5.69–02	2.03–06	9.69–05			5.70–02
2.00+00		4.86–02	1.29–06	3.86–04			4.89–02
3.00+00		3.82–02	7.18–07	1.11–03	1.33–05		3.93–02
4.00+00		3.19–02	4.89–07	1.80–03	5.47–05		3.37–02
5.00+00		2.75–02	3.73–07	2.41–03	1.08–04		3.00–02
6.00+00		2.43–02	2.97–07	2.95–03	1.65–04		2.74–02
8.00+00		1.99–02	2.13–07	3.86–03	2.83–04		2.40–02
1.00+01		1.69–02	1.66–07	4.60–03	3.87–04		2.19–02
1.50+01		1.25–02		6.00–03	6.03–04		1.92–02
2.00+01		1.01–02		7.03–03	7.73–04		1.79–02
3.00+01		7.33–03		8.47–03	1.03–03		1.68–02
4.00+01		5.82–03		9.46–03	1.22–03		1.65–02
5.00+01		4.86–03		1.02–02	1.37–03		1.64–02
6.00+01		4.19–03		1.08–02	1.49–03		1.65–02
8.00+01		3.30–03		1.17–02	1.68–03		1.67–02
1.00+02		2.75–03		1.24–02	1.82–03		1.70–02
1.50+02		1.95–03		1.35–02	2.07–03		1.75–02
2.00+02		1.53–03		1.42–02	2.24–03		1.79–02
3.00+02		1.09–03		1.50–02	2.46–03		1.85–02
4.00+02		8.50–04		1.54–02	2.60–03		1.89–02
5.00+02		7.04–04		1.58–02	2.70–03		1.92–02
6.00+02		6.02–04		1.60–02	2.78–03		1.94–02
8.00+02		4.70–04		1.63–02	2.89–03		1.97–02
1.00+03		3.87–04		1.65–02	2.97–03		1.99–02
1.50+03		2.70–04		1.68–02	3.10–03		2.02–02
2.00+03		2.09–04		1.69–02	3.18–03		2.03–02
3.00+03		1.46–04		1.71–02	3.27–03		2.05–02
4.00+03		1.12–04		1.72–02	3.32–03		2.06–02
5.00+03		9.18–05		1.73–02	3.36–03		2.07–02
6.00+03		7.79–05		1.73–02	3.38–03		2.08–02
8.00+03		6.00–05		1.74–02	3.41–03		2.08–02
1.00+04		4.90–05		1.74–02	3.43–03		2.09–02
1.50+04		3.38–05		1.74–02	3.46–03		2.09–02
2.00+04		2.60–05		1.75–02	3.48–03		2.10–02
3.00+04		1.79–05		1.75–02	3.49–03		2.10–02
4.00+04		1.38–05		1.75–02	3.50–03		2.10–02
5.00+04		1.12–05		1.75–02	3.51–03		2.10–02
6.00+04		9.48–06		1.75–02	3.51–03		2.10–02
8.00+04		7.27–06		1.75–02	3.52–03		2.10–02
1.00+05		5.91–06		1.75–02	3.52–03		2.11–02

Table 3.—32. POLYSTYRENE, $(C_8H_8O_2)_n$

Photon energy	Scattering		Photo-electric	Pair production		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00—02	3.13—01	2.08—01	1.82+00			2.13+00	2.03+00
1.50—02	2.64—01	2.04—01	4.91—01			7.55—01	6.95—01
2.00—02	2.39—01	2.00—01	1.86—01			4.24—01	3.86—01
3.00—02	2.13—01	1.94—01	4.63—02			2.59—01	2.40—01
4.00—02	1.99—01	1.88—01	1.76—02			2.17—01	2.05—01
5.00—02	1.90—01	1.82—01	8.95—03			1.99—01	1.91—01
6.00—02	1.83—01	1.77—01	5.33—03			1.88—01	1.82—01
8.00—02	1.71—01	1.68—01	2.09—03			1.73—01	1.70—01
1.00—01	1.62—01	1.60—01	1.00—03			1.63—01	1.61—01
1.50—01	1.45—01	1.44—01	2.67—04			1.45—01	1.44—01
2.00—01		1.32—01	1.06—04				1.32—01
3.00—01		1.15—01	2.99—05				1.15—01
4.00—01		1.03—01	1.28—05				1.03—01
5.00—01		9.38—02	6.91—06				9.38—02
6.00—01		8.68—02	4.30—06				8.68—02
8.00—01		7.63—02	2.17—06				7.63—02
1.00+00		6.85—02	1.34—06				6.85—02
1.50+00		5.57—02	6.26—07	7.64—05			5.58—02
2.00+00		4.75—02	3.99—07	3.05—04			4.78—02
3.00+00		3.74—02	2.23—07	8.76—04	1.30—05		3.83—02
4.00+00		3.12—02	1.53—07	1.42—03	5.36—05		3.27—02
5.00+00		2.69—02	1.17—07	1.91—03	1.05—04		2.90—02
6.00+00		2.38—02	9.32—08	2.34—03	1.62—04		2.63—02
8.00+00		1.95—02	6.68—08	3.06—03	2.77—04		2.28—02
1.00+01		1.66—02	5.19—08	3.65—03	3.79—04		2.06—02
1.50+01		1.23—02		4.77—03	5.90—04		1.76—02
2.00+01		9.86—03		5.59—03	7.57—04		1.62—02
3.00+01		7.17—03		6.74—03	1.01—03		1.49—02
4.00+01		5.70—03		7.54—03	1.19—03		1.44—02
5.00+01		4.76—03		8.14—03	1.34—03		1.42—02
6.00+01		4.10—03		8.62—03	1.46—03		1.42—02
8.00+01		3.23—03		9.34—03	1.65—03		1.42—02
1.00+02		2.69—03		9.87—03	1.79—03		1.44—02
1.50+02		1.91—03		1.08—02	2.04—03		1.47—02
2.00+02		1.50—03		1.13—02	2.20—03		1.50—02
3.00+02		1.06—03		1.20—02	2.42—03		1.55—02
4.00+02		8.32—04		1.24—02	2.57—03		1.58—02
5.00+02		6.89—04		1.27—02	2.67—03		1.60—02
6.00+02		5.90—04		1.29—02	2.75—03		1.62—02
8.00+02		4.61—04		1.31—02	2.86—03		1.65—02
1.00+03		3.79—04		1.33—02	2.94—03		1.66—02
1.50+03		2.65—04		1.36—02	3.07—03		1.69—02
2.00+03		2.05—04		1.37—02	3.15—03		1.71—02
3.00+03		1.43—04		1.39—02	3.25—03		1.73—02
4.00+03		1.10—04		1.39—02	3.31—03		1.74—02
5.00+03		8.99—05		1.40—02	3.34—03		1.74—02
6.00+03		7.62—05		1.40—02	3.37—03		1.75—02
8.00+03		5.87—05		1.41—02	3.40—03		1.75—02
1.00+04		4.79—05		1.41—02	3.42—03		1.76—02
1.50+04		3.31—05		1.42—02	3.45—03		1.76—02
2.00+04		2.55—05		1.42—02	3.47—03		1.77—02
3.00+04		1.76—05		1.42—02	3.49—03		1.77—02
4.00+04		1.35—05		1.42—02	3.50—03		1.77—02
5.00+04		1.10—05		1.42—02	3.51—03		1.77—02
6.00+04		9.28—06		1.42—02	3.51—03		1.77—02
8.00+04		7.12—06		1.42—02	3.52—03		1.78—02
1.00+05		5.79—06		1.42—02	3.52—03		1.78—02

Table 3.–33. POLYMETHYL METHACRYLATE (Lucite), $(C_5H_8O_2)_n$

Photon energy	Scattering		Photo-electric	Pair production		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00–02	3.42–01	2.08–01	2.90+00			3.25+00	3.11+00
1.50–02	2.79–01	2.04–01	7.78–01			1.06+00	9.82–01
2.00–02	2.48–01	2.01–01	3.03–01			5.51–01	5.03–01
3.00–02	2.18–01	1.94–01	7.98–02			2.98–01	2.74–01
4.00–02	2.03–01	1.88–01	3.12–02			2.34–01	2.19–01
5.00–02	1.92–01	1.83–01	1.54–02			2.08–01	1.98–01
6.00–02	1.84–01	1.77–01	8.86–03			1.93–01	1.86–01
8.00–02	1.72–01	1.68–01	3.50–03			1.76–01	1.72–01
1.00–01	1.63–01	1.60–01	1.68–03			1.64–01	1.62–01
1.50–01	1.46–01	1.44–01	4.52–04			1.46–01	1.45–01
2.00–01	1.33–01	1.32–01	1.81–04			1.33–01	1.32–01
3.00–01	1.15–01	1.15–01	5.14–05			1.15–01	1.15–01
4.00–01	1.03–01	1.03–01	2.19–05			1.03–01	1.03–01
5.00–01	9.41–02	9.41–02	1.18–05			9.41–02	9.41–02
6.00–01	8.71–02	8.70–02	7.39–06			8.71–02	8.70–02
8.00–01		7.65–02	3.72–06				7.65–02
1.00+00		6.87–02	2.30–06				6.87–02
1.50+00		5.59–02	1.08–06	8.49–05			5.59–02
2.00+00		4.77–02	6.85–07	3.38–04			4.80–02
3.00+00		3.75–02	3.83–07	9.72–04	1.31–05		3.85–02
4.00+00		3.13–02	2.62–07	1.58–03	5.37–05		3.29–02
5.00+00		2.70–02	2.00–07	2.12–03	1.06–04		2.92–02
6.00+00		2.39–02	1.59–07	2.59–03	1.62–04		2.66–02
8.00+00		1.95–02	1.14–07	3.39–03	2.78–04		2.32–02
1.00+01		1.66–02	8.92–08	4.05–03	3.80–04		2.11–02
1.50+01		1.23–02		5.29–03	5.91–04		1.82–02
2.00+01		9.88–03		6.19–03	7.59–04		1.68–02
3.00+01		7.19–03		7.46–03	1.01–03		1.57–02
4.00+01		5.72–03		8.34–03	1.20–03		1.53–02
5.00+01		4.77–03		9.00–03	1.35–03		1.51–02
6.00+01		4.11–03		9.54–03	1.47–03		1.51–02
8.00+01		3.24–03		1.03–02	1.65–03		1.52–02
1.00+02		2.69–03		1.09–02	1.79–03		1.54–02
1.50+02		1.92–03		1.19–02	2.04–03		1.59–02
2.00+02		1.50–03		1.25–02	2.20–03		1.62–02
3.00+02		1.06–03		1.32–02	2.42–03		1.67–02
4.00+02		8.34–04		1.37–02	2.56–03		1.71–02
5.00+02		6.90–04		1.40–02	2.67–03		1.73–02
6.00+02		5.91–04		1.42–02	2.74–03		1.75–02
8.00+02		4.62–04		1.45–02	2.86–03		1.78–02
1.00+03		3.80–04		1.46–02	2.94–03		1.80–02
1.50+03		2.65–04		1.49–02	3.06–03		1.82–02
2.00+03		2.05–04		1.51–02	3.14–03		1.84–02
3.00+03		1.43–04		1.52–02	3.24–03		1.86–02
4.00+03		1.10–04		1.53–02	3.29–03		1.87–02
5.00+03		9.01–05		1.54–02	3.33–03		1.88–02
6.00+03		7.64–05		1.54–02	3.35–03		1.88–02
8.00+03		5.89–05		1.55–02	3.38–03		1.89–02
1.00+04		4.81–05		1.55–02	3.40–03		1.89–02
1.50+04		3.32–05		1.55–02	3.43–03		1.90–02
2.00+04		2.55–05		1.56–02	3.45–03		1.90–02
3.00+04		1.76–05		1.56–02	3.47–03		1.91–02
4.00+04		1.35–05		1.56–02	3.48–03		1.91–02
5.00+04		1.10–05		1.56–02	3.48–03		1.91–02
6.00+04		9.31–06		1.56–02	3.49–03		1.91–02
8.00+04		7.14–06		1.56–02	3.49–03		1.91–02
1.00+05		5.80–06		1.56–02	3.50–03		1.91–02

Table 3.-34. POLYETHYLENE, $(CH_2)_n$

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00–02	3.18–01	2.20–01	1.69+00			2.01+00	1.91+00
1.50–02	2.72–01	2.16–01	4.56–01			7.28–01	6.72–01
2.00–02	2.48–01	2.13–01	1.73–01			4.20–01	3.85–01
3.00–02	2.23–01	2.06–01	4.30–02			2.66–01	2.49–01
4.00–02	2.10–01	1.99–01	1.63–02			2.26–01	2.15–01
5.00–02	2.00–01	1.93–01	8.30–03			2.09–01	2.01–01
6.00–02	1.93–01	1.88–01	4.95–03			1.98–01	1.93–01
8.00–02	1.81–01	1.78–01	1.94–03			1.83–01	1.80–01
1.00–01	1.71–01	1.69–01	9.29–04			1.72–01	1.70–01
1.50–01	1.54–01	1.53–01	2.47–04			1.54–01	1.53–01
2.00–01		1.40–01	9.85–05				1.40–01
3.00–01		1.22–01	2.78–05				1.22–01
4.00–01		1.09–01	1.19–05				1.09–01
5.00–01		9.95–02	6.41–06				9.95–02
6.00–01		9.21–02	3.99–06				9.21–02
8.00–01		8.09–02	2.01–06				8.09–02
1.00+00		7.27–02	1.24–06				7.27–02
1.50+00		5.91–02	5.81–07	7.28–05			5.92–02
2.00+00		5.04–02	3.70–07	2.91–04			5.07–02
3.00+00		3.96–02	2.07–07	8.35–04	1.38–05		4.05–02
4.00+00		3.31–02	1.42–07	1.35–03	5.68–05		3.45–02
5.00+00		2.86–02	1.08–07	1.82–03	1.12–04		3.05–02
6.00+00		2.53–02	8.65–08	2.23–03	1.72–04		2.77–02
8.00+00		2.07–02	6.20–08	2.92–03	2.94–04		2.39–02
1.00+01		1.76–02	4.82–08	3.48–03	4.02–04		2.15–02
1.50+01		1.30–02		4.55–03	6.26–04		1.82–02
2.00+01		1.05–02		5.33–03	8.03–04		1.66–02
3.00+01		7.61–03		6.42–03	1.07–03		1.51–02
4.00+01		6.05–03		7.19–03	1.27–03		1.45–02
5.00+01		5.05–03		7.76–03	1.42–03		1.42–02
6.00+01		4.35–03		8.22–03	1.55–03		1.41–02
8.00+01		3.43–03		8.91–03	1.75–03		1.41–02
1.00+02		2.85–03		9.42–03	1.90–03		1.42–02
1.50+02		2.03–03		1.03–02	2.17–03		1.45–02
2.00+02		1.59–03		1.08–02	2.34–03		1.47–02
3.00+02		1.13–03		1.15–02	2.58–03		1.52–02
4.00+02		8.82–04		1.19–02	2.73–03		1.55–02
5.00+02		7.30–04		1.21–02	2.85–03		1.57–02
6.00+02		6.25–04		1.23–02	2.93–03		1.59–02
8.00+02		4.88–04		1.26–02	3.05–03		1.61–02
1.00+03		4.02–04		1.27–02	3.14–03		1.63–02
1.50+03		2.81–04		1.30–02	3.28–03		1.65–02
2.00+03		2.17–04		1.31–02	3.36–03		1.67–02
3.00+03		1.51–04		1.33–02	3.46–03		1.69–02
4.00+03		1.17–04		1.33–02	3.52–03		1.70–02
5.00+03		9.53–05		1.34–02	3.56–03		1.70–02
6.00+03		8.08–05		1.34–02	3.59–03		1.71–02
8.00+03		6.23–05		1.35–02	3.62–03		1.72–02
1.00+04		5.08–05		1.35–02	3.64–03		1.72–02
1.50+04		3.51–05		1.35–02	3.68–03		1.73–02
2.00+04		2.70–05		1.36–02	3.70–03		1.73–02
3.00+04		1.86–05		1.36–02	3.72–03		1.73–02
4.00+04		1.43–05		1.36–02	3.73–03		1.73–02
5.00+04		1.16–05		1.36–02	3.73–03		1.73–02
6.00+04		9.84–06		1.36–02	3.74–03		1.74–02
8.00+04		7.55–06		1.36–02	3.74–03		1.74–02
1.00+05		6.14–06		1.36–02	3.75–03		1.74–02

Table 3.–35. BAKELITE (Typical), $(C_{45}H_{38}O_7)_n$

Photon energy	Scattering		Photoelectric	Pair production		Total	
	With coherent	Without coherent		Nuclear field	Electron field	With coherent	Without coherent
MeV	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g
1.00–02	3.27–01	2.04–01	2.43+00			2.76+00	2.64+00
1.50–02	2.69–01	2.00–01	6.53–01			9.23–01	8.54–01
2.00–02	2.41–01	1.97–01	2.52–01			4.92–01	4.48–01
3.00–02	2.12–01	1.90–01	6.50–02			2.77–01	2.55–01
4.00–02	1.98–01	1.84–01	2.51–02			2.23–01	2.09–01
5.00–02	1.88–01	1.79–01	1.26–02			2.00–01	1.91–01
6.00–02	1.80–01	1.74–01	7.31–03			1.87–01	1.81–01
8.00–02	1.68–01	1.65–01	2.88–03			1.71–01	1.68–01
1.00–01	1.59–01	1.57–01	1.38–03			1.61–01	1.58–01
1.50–01	1.42–01	1.41–01	3.70–04			1.43–01	1.42–01
2.00–01	1.30–01	1.29–01	1.48–04			1.30–01	1.30–01
3.00–01		1.13–01	4.19–05				1.13–01
4.00–01		1.01–01	1.79–05				1.01–01
5.00–01		9.21–02	9.66–06				9.21–02
6.00–01		8.52–02	6.02–06				8.52–02
8.00–01		7.49–02	3.04–06				7.49–02
1.00+00		6.73–02	1.88–06				6.73–02
1.50+00		5.47–02	8.78–07	8.20–05			5.48–02
2.00+00		4.67–02	5.59–07	3.27–04			4.70–02
3.00+00		3.67–02	3.13–07	9.40–04	1.28–05		3.77–02
4.00+00		3.06–02	2.13–07	1.53–03	5.26–05		3.22–02
5.00+00		2.64–02	1.63–07	2.05–03	1.03–04		2.86–02
6.00+00		2.34–02	1.30–07	2.50–03	1.59–04		2.60–02
8.00+00		1.91–02	9.32–08	3.28–03	2.72–04		2.27–02
1.00+01		1.63–02	7.27–08	3.91–03	3.72–04		2.06–02
1.50+01		1.21–02		5.12–03	5.79–04		1.78–02
2.00+01		9.67–03		5.99–03	7.43–04		1.64–02
3.00+01		7.04–03		7.22–03	9.90–04		1.53–02
4.00+01		5.60–03		8.07–03	1.17–03		1.48–02
5.00+01		4.67–03		8.72–03	1.32–03		1.47–02
6.00+01		4.02–03		9.23–03	1.44–03		1.47–02
8.00+01		3.17–03		1.00–02	1.62–03		1.48–02
1.00+02		2.64–03		1.06–02	1.76–03		1.50–02
1.50+02		1.88–03		1.15–02	2.00–03		1.54–02
2.00+02		1.47–03		1.21–02	2.16–03		1.57–02
3.00+02		1.04–03		1.28–02	2.37–03		1.62–02
4.00+02		8.17–04		1.33–02	2.51–03		1.66–02
5.00+02		6.76–04		1.35–02	2.61–03		1.68–02
6.00+02		5.79–04		1.37–02	2.69–03		1.70–02
8.00+02		4.52–04		1.40–02	2.80–03		1.73–02
1.00+03		3.72–04		1.42–02	2.88–03		1.74–02
1.50+03		2.60–04		1.45–02	3.00–03		1.77–02
2.00+03		2.01–04		1.46–02	3.08–03		1.79–02
3.00+03		1.40–04		1.48–02	3.17–03		1.81–02
4.00+03		1.08–04		1.49–02	3.23–03		1.82–02
5.00+03		8.82–05		1.49–02	3.26–03		1.83–02
6.00+03		7.48–05		1.50–02	3.29–03		1.83–02
8.00+03		5.76–05		1.50–02	3.32–03		1.84–02
1.00+04		4.71–05		1.50–02	3.34–03		1.84–02
1.50+04		3.25–05		1.51–02	3.37–03		1.85–02
2.00+04		2.50–05		1.51–02	3.39–03		1.85–02
3.00+04		1.72–05		1.51–02	3.41–03		1.85–02
4.00+04		1.32–05		1.51–02	3.42–03		1.86–02
5.00+04		1.08–05		1.51–02	3.42–03		1.86–02
6.00+04		9.11–06		1.52–02	3.43–03		1.86–02
8.00+04		6.99–06		1.52–02	3.43–03		1.86–02
1.00+05		5.68–06		1.52–02	3.44–03		1.86–02

Table 3.–36. PYREX GLASS, (Corning 7740)

Photon energy	Scattering: With coherent	Scattering: Without coherent	Photo-electric	Pair production: Nuclear field	Pair production: Electron field	Total: With coherent	Total: Without coherent
MeV	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*	*cm²/g*
1.00–02	5.36–01	1.92–01	1.65+01			1.71+01	1.67+01
1.50–02	3.79–01	1.88–01	4.76+00			5.14+00	4.95+00
2.00–02	3.06–01	1.85–01	1.94+00			2.25+00	2.13+00
3.00–02	2.40–01	1.79–01	5.46–01			7.86–01	7.24–01
4.00–02	2.10–01	1.73–01	2.21–01			4.31–01	3.94–01
5.00–02	1.93–01	1.68–01	1.09–01			3.02–01	2.77–01
6.00–02	1.81–01	1.63–01	6.15–02			2.42–01	2.25–01
8.00–02	1.65–01	1.55–01	2.47–02			1.90–01	1.80–01
1.00–01	1.54–01	1.47–01	1.21–02			1.66–01	1.60–01
1.50–01	1.36–01	1.33–01	3.34–03			1.39–01	1.36–01
2.00–01	1.23–01	1.22–01	1.36–03			1.25–01	1.23–01
3.00–01	1.07–01	1.06–01	3.95–04			1.07–01	1.06–01
4.00–01	9.53–02	9.48–02	1.71–04			9.54–02	9.50–02
5.00–01	8.69–02	8.66–02	9.23–05			8.70–02	8.67–02
6.00–01	8.03–02	8.01–02	5.77–05			8.04–02	8.02–02
8.00–01		7.04–02	2.91–05				7.04–02
1.00+00		6.33–02	1.80–05				6.33–02
1.50+00		5.14–02	8.43–06	1.40–04			5.16–02
2.00+00		4.39–02	5.35–06	5.53–04			4.44–02
3.00+00		3.45–02	2.96–06	1.58–03	1.20–05		3.61–02
4.00+00		2.88–02	2.01–06	2.56–03	4.95–05		3.14–02
5.00+00		2.49–02	1.46–06	3.43–03	9.72–05		2.84–02
6.00+00		2.20–02	1.22–06	4.20–03	1.49–04		2.63–02
8.00+00		1.80–02	8.71–07	5.49–03	2.56–04		2.37–02
1.00+01		1.53–02	6.82–07	6.54–03	3.50–04		2.22–02
1.50+01		1.13–02		8.52–03	5.44–04		2.04–02
2.00+01		9.10–03		9.96–03	6.99–04		1.98–02
3.00+01		6.62–03		1.20–02	9.31–04		1.95–02
4.00+01		5.26–03		1.34–02	1.10–03		1.98–02
5.00+01		4.39–03		1.45–02	1.24–03		2.01–02
6.00+01		3.78–03		1.53–02	1.34–03		2.04–02
8.00+01		2.98–03		1.65–02	1.51–03		2.10–02
1.00+02		2.48–03		1.74–02	1.63–03		2.15–02
1.50+02		1.76–03		1.89–02	1.84–03		2.25–02
2.00+02		1.38–03		1.98–02	1.99–03		2.32–02
3.00+02		9.80–04		2.09–02	2.17–03		2.40–02
4.00+02		7.68–04		2.15–02	2.29–03		2.45–02
5.00+02		6.36–04		2.19–02	2.38–03		2.49–02
6.00+02		5.44–04		2.22–02	2.44–03		2.52–02
8.00+02		4.25–04		2.26–02	2.54–03		2.56–02
1.00+03		3.50–04		2.29–02	2.60–03		2.58–02
1.50+03		2.44–04		2.32–02	2.71–03		2.62–02
2.00+03		1.89–04		2.34–02	2.78–03		2.64–02
3.00+03		1.31–04		2.37–02	2.85–03		2.67–02
4.00+03		1.01–04		2.38–02	2.90–03		2.68–02
5.00+03		8.29–05		2.39–02	2.92–03		2.69–02
6.00+03		7.03–05		2.39–02	2.94–03		2.69–02
8.00+03		5.42–05		2.40–02	2.97–03		2.70–02
1.00+04		4.42–05		2.40–02	2.98–03		2.71–02
1.50+04		3.06–05		2.41–02	3.01–03		2.71–02
2.00+04		2.35–05		2.41–02	3.02–03		2.72–02
3.00+04		1.62–05		2.42–02	3.04–03		2.72–02
4.00+04		1.24–05		2.42–02	3.04–03		2.72–02
5.00+04		1.01–05		2.42–02	3.05–03		2.72–02
6.00+04		8.57–06		2.42–02	3.05–03		2.73–02
8.00+04		6.57–06		2.42–02	3.06–03		2.73–02
1.00+05		5.34–06		2.42–02	3.06–03		2.73–02

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